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2025 Victoria Ave., Regina
Saskatchewan. S4P 0S1

A TECHNICAL AND ECONOMIC ASSESSMENT OF THE REACTIVITY OF SASKATCHEWAN LIGNITE COALS AS THEY RELATE TO GASIFICATION PROCESSES PHASE III

S. P. Van Der Heijden
D. R. Andrews
A. J. Szladow

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Project Leader: S.P. Van Der Heijden

Project Manager: A J. Saladow

Director of R & D Centre: M.F. Barabas

EXECUTIVE SUMMARY

The composition of condensates collected during the gasification of Saskatchewan lignite coals compares well with the composition of gasifier sluice water and quench water obtained from large-scale fixed-bed gasifiers. Comparison of heavy element concentrations with concentrations allowable under the Canadian Drinking Water Objectives and the U.S. Standards shows that only those for arsenic (As), Boron (B) and Chromium (Cr) are exceeded. The high chromium levels are thought to arise from the reactor due to a high surface area to volume ratio in bench scale reactors. Indeed chromium concentrations in the Wellman-Galusha (Ft. Snelling) gasifier ash sluice water and cyclone dust quench water are an order of magnitude below the Canadian Drinking Water objectives and American primary standard.

The higher arsenic and boron levels are thought to be directly related to their high levels in the Canadian lignites. Arsenic shows low toxicity to plant, animal and aquatic life forms and its major threat is likely to the micro-organism used in the biox treatment facilities.

The organic content of the condensate is similar to that observed for other fixed-bed gasifiers. The average phenol/TOC ratio of 0.83 for all runs is in good agreement with the ratio of 0.82 obtained for the slagging fixed-bed gasifier at the Grand Forks Research Centre. The phenol/TOC ratio's for the Synthane PDU and Hygas gasification facilities are 0.265 and 0.292 respectively.

Elements such as: mercury (Hg), selenium (Se), lead (Pb), fluorine (F) and antimony (Sb), do not show an enrichment in the ash residue as compared to their levels in the parent coal. This indicates a high degree of volatility for these elements. Arsenic does not show this anticipated effect. The only potential environmental problems associated with gasifier ash are those of leaching and are similar in nature to those encountered in ash disposal from conventional coal fired facilities.

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1. INTRODUCTION

Accurate environmental data can only be obtained from large operating plants. However, there are many areas in which additional knowledge of pollution parameters can be obtained through research conducted on a smaller scale. For instance, pilot plant results obtained for the CO_2 acceptor process have shown low levels for heavier hydrocarbons in the raw gas. At present there is no satisfactory explanation for this phenomenon, but if process conditions can be adjusted to reduce the output of such materials, this could have a substantial effect on pollution control costs.

Much additional information on trace element distribution is needed. This not only includes their form which affects solubility, leachibility, reactivity, etc., but also which of the various process streams are affected. Since not all forms of trace elements are toxic, it is important to know which compounds are hazardous as well as which compounds are formed and/or emitted during gasification.

In this work the fate of several potentially hazardous trace elements was determined using a bench-scale fixed bed reactor. The results obtained for the effluent streams were compared with several full scale and pilot gasifiers.

In a recent study on the impact of the U.S. Resource Conservation and Recovery Act on coal gasification wastes, Hart and Delaney (1979) identified ash and char as the waste streams likely to pose the greatest

potential hazard. Other hazardous wastestreams, in decreasing significance, were air pollution control (in part due to their large volumes), inorganic solids and sludges from acid gas removal and air and water pollution control (scrubber sludge, acid gas removal sludge), and spent catalyst waste.

The work in this report will mainly concentrate on solid gasification residue and scrubber/quench waste streams.

2. HAZARDOUS WASTES

2.1. Environmental Impact of Coal Gasification Facilities

There currently exist, neither in Canada nor in the U.S.A., environmental standards which apply directly to waste water discharges or atmospheric emissions from coal gasification plants. Effluent limitations exist for the petroleum refining, by-product coke industries and fossil fueled electrical utilities (Appendix A, Appendix D). However, despite some similarities, the coal gasification facilities are quite different and limitations might differ significantly.

Coal gasification is essentially a closed chemical system and major sources of airborne emissions are generally fugitive in nature. The probability rating (Cavanaugh, et. al., 1975) for fugitive air emissions in coal gasification is given in Table 2.1. The impact of coal gasification plant emissions to the atmosphere will largely depend on:

1) Gasifier design and operating parameters.
2) Rank and source of coal used in gasification.
3) Coal gas treatment steps employed.
4) Quality and ultimate use of the product gas.

The nature and source of the major waste streams associated with the gasification of coal as identified by the U.S. Environmental Protection Agency are given in Table 2.2.

Table 2.1. PROBABILITY RATING FOR FUGITIVE AIR EMISSIONS IN COAL GASIFICATION BY PROCESS (Cavanaugh, et. al. 1975).

Process	Process Stream Characteristics					
	Pressure	Temperature	Potentially Hazardous Volatiles	Corrosiveness	General Housekeeping	Potantial for Hazardous Fugitive Emissions
Coal Preparation	low	low	med	low	poor	med
Oxygen blown gasification	high	high	high	med-high	med	med-high
Quenching and cooling	low	med-high	high	high	med	med-high
Tar separation	low	low	high	med	poor	high
Shift conversion	high	high	low	low	good	low-med
Phenol recovery	low	med	high	med	med	med
Acid gas removal	low	low	high	low	med	med
Methanation	high	high	med	low	good	med
Further gas purification	low	low	med	low	med	med
Sulfur recovery	low	low	med	low	med	low-med
Air blown gasification	high	high	high	med-high	med	med-high
Storage	low	low	med	low	med	med

Table 2.2. NATURE AND SOURCE OF MAJOR WASTE STREAM ASSOCIATED WITH THE GASIFICATION OF COAL
(Emission from processes producing clean fuels (1974) EPA-450/3-73 028)

Waste Stream	Principle Components	Source	Disposition	Process
Coal Dust	Coal Particles	Feedstock Crushing and Grinding	Containment and Recovery	Cyclone Separators, Bagfilters, Enclosure
Stack Gas	CO_2, SO_2, N_2, O_2	Steam Generation Stackgas Clean-up	Treatment/ Discharge	Welman-Lord, Limestone Injection, Lime Scrubbing, Catalytic Oxidation, Double Alkali, Citrate
	Nitrogen	Oxygen Generation	Discharge	
Acid Gas	H_2, CO_2, CH_2, COS, H_2S, H_2	Product of Shift Conversion	Sulfur Recovery	H_2S can be selectively removed from a gas stream by a Rectisol, Hot Potassium Carbonate, Sulfinol, MEA, DIPA, or similar process. Claus and Stretford process recover elemental sulfur from H_2S rich streams. Tail gases from these units can be heated by incineration Deavon, Welman-Lord or Scott processes.
Exhaust	CO, HC, NO_x, Particulates	Automobile Traffic	Discharge	
Runoff Leachings	Pyrites, Sediments, Oil, Organic Matter	Feedstock, Storage Ash Ponds,	Treatment/ Utilization	Neutralization
		Land Surface	Discharge	Settling

Table 2.2 (continued)

Waste Stream	Principal Components	Source	Disposition	Process
Waste Water	Dissolved salts, NH_3 Phenols, Cyanide, Thyocianate, BTX	Water Treatment Gasification Product of Shift Conversion	Treatment/ Utilization Treatment and Rinse	Coagulation (Chevron, Phenosolvan, Biological Oxidation)
		Methanation		
Blowdown	Dissolved Salts	Boilers/Cooling Towers	Treatment and Rinse	Chevron, Phenosolvan, Bio-oxidation
Cooling Water	Heat	Heat exchangers	Utilization Discharge	Waste Heat Recoverer, Cooling Tower
Sanitary Sewage	Organic/Nitrogen Compounds	Washrooms	Treatment and Utilization	Biological Oxidation
Rocks and Debris		Feedstock Cleaning	Disposal/ Utilization	Landfill construction material
Tar	COD, DS, SS, CO, CH_4 Phenols, NH_3, HCH Thyocinate, H_2S	Gasification	Utilization	Conversion to oil, direct gasification
Char	Fixed carbon, sulfur	Gasification	Disposal/ Utilization	Gasification, desulfurization, direct combustion
Ash	Inert residue	Gasification Steam Generation	Disposal/ Utilization	Landfill incorporation in construction materials
Spent Catalysts	Cobalt, Molybdenum Iron Bauxite Nickel	Shift conversion	Treatment and disposal	Oxidation
		Sulfur recovery Methanation	Treatment and disposal	

Table 2.2 (continued)

Waste Stream	Principal Components	Source	Disposition	Process
Spent Purifying Media	Iron or Zincoxide	Final Purification	Treatment and Disposal	Oxidation
Sludge	Spent Ccarbon Sulfites	Final Purification	Disposal	
		Stack Gas Cleanup	Treatment and Disposal	
Refuse	Solids, Biomass	Waste Water Treatment	Treatment and Disposal	Dewatering, Oxidation, Landfilling
		Work Areas	Treatment and Disposal	Incineration, Landfilling

The airborne and waterborne emissions of a coal gasification plant may contain substances which could have a serious impact on human health. Both a variety of complex hydrocarbons and heavy metals may be emitted by gasification facilities. The hydrocarbons which include polycyclic organics are listed in Table 2.3. However, it should be stressed that gasification is a closed process and that emissions will be considerably less than those observed in coking plants.

Since there is a lack of experience in both Canada and the U.S. with coal gasification plants, the quantities and significance of emissions are not well established nor understood. For this reason there is very little background data related to specific health impacts from these emissions. Nevertheless, some evaluation can be made by review of evidence gathered for coking plants, electric generating stations, and other facilities that emit similar constituents.

2.2. Toxicity and Potential for Environmental Damage from Selected Pollutants

2.2.1 Trace Element Emissions

The content of trace elements in coal varies for different regions and different rank of coal. The potential for trace element emissions will therefore vary with the type of coal as well as the gasification process used. Considerable data on trace elements for most coals are available; however, the composition of a particular coal must be determined, because most data available are not site specific. Table 2.4 gives the ranges of potentially volatile trace elements for

Table 2.3. POTENTIALLY HAZARDOUS SUBSTANCES SUSPECTED PRESENT IN COAL CONVERSION PROCESS STREAMS (Cavanaugh, 1975)

Chemical Classification	Compound	Phase
Acids and Anhydrides	Maleic acid	Liquid
	Cresylic acid	Liquid
	Sulfuric acid	Liquid
	Anthraquinone disulfuric acid	Liquid
Alcohols	Aliphatic alcohols	Liquid
	Aromatic alcohols	Liquid
Amines	Diethylamines	Gas
	Methylethylamines	Gas
	Ammonia	Gas/Liquid
Inorganic Salts	Ammonium sulfate	Liquid
Carbonyl Compounds	Ketones	Gas/Liquid
	Aldehydes	Gas/Liquid
Combustion Gases	Carbon monoxide	Gas
	Sulfur oxides	Gas
	Nitrogen oxides	Gas
Heterocyclics	Pyridines	Gas/Liquid
	Pyrroles	Gas/Liquid
	(Mono) Benzofuranes	Gas
Hydrocarbons	Benzene	Gas
	Toluene	Gas
	Xylene	Gas
	Ethylcyclopentane	Gas
	Decane	Gas
	Undecane	Gas
	Dodecane	Gas
	Naphthalene	Gas
	Ethylbenzene	Gas
	Propylbenzene	Gas
	Ethyltoluene	Gas
	Trimethylbenzene	Gas
	Olefins	Gas
Phenols	Phenols	Gas/Liquid
	Dimethyl phenol	Liquid
	Cresols	Gas/Liquid
	Xylenols	Gas/Liquid
	Phenyl phenols	Gas
	Alkyl phenols	Gas
	Alkyl cresols	Gas
	Ethyl phenols	Gas
	Propyl phenols	Gas
	Methylethyl phenols	Gas
	Indanols	Gas
	Beta-naphthol	Gas
	Pyrocatechol	Gas
	Resorcinol	Gas
	Methyl Resorcinol	Gas

Table 2.4. RANGES OF CHEMICAL CONSTITUENTS OF REPRESENTATIVE NORTH AMERICAN COALS
(Ruch, et. al., 1974)

Item	Range %	Item	Range µg/g
Major Constituents		**Trace Elements**	
C	55.2 - 80.1	As	0.5 - 93.0
H	4.0 - 5.8	B	5.0 - 224.0
N	0.8 - 1.8	Be	0.2 - 4.0
O	4.2 - 16.0	Br	4.0 - 52.0
		Cd	0.1 - 65.0
Major Characteristics		Co	1.0 - 43.0
		Cr	4.0 - 54.0
Air Dry Loss	1.4 - 16.7	Cu	5.0 - 61.0
Moisture	0.1 - 20.7	F	25.0 - 143.0
Volatility	18.9 - 65.4	Ga	1.1 - 7.5
C, fixed	34.6 - 65.4	Ge	1.0 - 43.0
Ash	2.2 - 25.8	Hg	0.02 - 1.6
		Mn	6.0 - 181.0
Minor Constituents		Mo	1.0 - 30.0
		Ni	3.0 - 80.0
Al	0.42 - 3.0	P	5.0 - 400.0
Ca	0.05 - 2.7	Pb	4.0 - 218.0
Cl	0.01 - 0.5	Sb	0.2 - 8.9
Fe	0.3 - 4.3	Se	0.4 - 7.7
K	0.02 - 0.4	Sn	1.0 - 51.0
Mg	0.01 - 0.2	V	11.0 - 78.0
Na	0.00 - 0.2	Zn	6.0 - 535.0
Si	0.58 - 6.1	Zr	8.0 - 133.0
Ti	0.02 - 0.2		
S, organic	0.3 - 3.1		
S, pyritic	0.06 - 3.8		
S, SO_4	0.01 - 1.1		
S, total	0.4 - 6.5		
S, X-ray	0.5 - 5.4		

North American coals.

2.2.2. Toxicology of Selected Trace Elements

The toxicity of coal-based trace elements is currently of environmental concern. Increased health risks are being associated with those elements which are highly volatilized during gasification (e.g., mercury, arsenic, selenium) or those which are discharged as submicron particulates (e.g., lead, cadmium and nickel). A list of possible problems associated with several trace elements is given in Table 2.5.

The potential hazard of coal-related trace element pollution lies in its significant contribution to atmospheric pollution in general and its resultant long term low level exposures. Trace element toxicity has escaped early diagnosis, because in cases where it was not suspected, it often went undetected. Establishing casual relationships between trace element exposure and specific pathological processes is difficult. Variations in population susceptibility and the existence and interference of the geological background of trace elements make the understanding of the environmental health aspects of trace element pollution a multidimensional problem. Many heavy metals, however, share common properties which may serve as a basis for their toxicity. Mercury, cadmium and lead for example, all inhibit a large number of enzymes having functional-SH groups (Valle and Ulmer, 1972). Heavy metal metabolic injury, in addition to producing primary toxicity, can adversely alter drug detoxification mechanisms (Hadley, et. al., 1974; Fouts and Pohl, 1971), with possible secondary consequences for people

Table 2.5. POSSIBLE HEALTH PROBLEMS ASSOCIATED WITH TRACE METALS

Metal or Metal Compound	Health Problems	Reference
Nickel carbonyl	Suspected carcinogenesis	(Sunderman and Donnelly, 1965); (Cavanaugh, 1975)
Antimony, Arsenic, Radmium, Cobalt, Copper, Iron, Lead, Magnesium, Manganese, Tin and Zinc oxides	Fume fever	(Waldbott, 1973)
Nickel	Nasal cancers	(Gilman and Ruckerbauer, 1963)
Cadmium	Prostrate cancer	(Potts, 1965); (Kipling and Waterhouse, 1967)
Chromium and compounds	Carcinogenesis	(Hueper, 1961)
Berylium and compounds	Carcinogenesis Poisoning	(Reeves, et. al., 1967); (Wager, et. al., 1969); (Nishimura, 1966)
Arsenic	Cancer of the skin Poisoning	(Wickstrom, 1972) (Lee and Fraumeni, 1969)
Cobalt	Carcinogenesis	(Gilman and Ruckerbauer, 1963)
Lead and Compounds	Nasal Cancers Kidney Damage	(Zawirsica and Medras, 1968) (Follinger, 1953)
Mercury and Compounds	Mutagenic and Teratogenic Effects	(D'Itri, 1972)
Vanadium	Inbitrition of Lipid Formation	(Stockinger, 1963)

on medication.

From a toxicologic viewpoint, the classification of trace elements into essential and non-essential has probably been overemphasized since both categories produce toxicity (Piperno, 1975). Excess of a trace element can produce toxicity by decreasing the availability and utilization of another. Excess molybdenum aggravates copper deficiency anemia in ruminants (Dowdy and Matrone, 1968), excess zinc induces copper deficiency in rats (Smith and Larson, 1946), excess calcium induces zinc deficiency in pigs (O'Dell, 1969), and increases the magnesium requirement in growing chicks (O'Dell, 1972), and excess cadmium induces negative calcium balance in man and copper deficiency in the rat (Piperno, 1975).

Factors affecting trace element toxicity are bound by the pharmacological principles affecting the toxicity of any chemical. These factors are the dose or concentration, exposure time, absorption route, organ distribution, metabolic fate, and the organism's defence mechanism in general. Heavy metals pose a significant threat, because they tend to have long biological half-lives. Stable aerosals of fine particulates contribute to the greatest health risk because of the likelihood of pulmonary absorption. Correlations between trace element pollution and their concentrations in biological fluids or tissue have been documented for arsenic (Milham and Strong, 1974), and lead (Needleman and Shapiro, 1973).

Volatile elements commonly considered to be most hazardous are: Be, F, As, Se, Cd, Pb and Hg (Hall, et. al., 1973). The physical and chemical form of a trace element pollutant at the time of body penetration is important in the total assessment of associated health risks. For example, elemental arsenic (Louria, et. al., 1972), beryllium (Piperno, 1975) are non-toxic to man as compared with their salts (Torrey, 1978; Waldbott, 1973). Elemental mercury is highly toxic when in vapour form (Wood, et. al., 1968) but not when injected orally (Schroeder, 1971). Mercury is a cumulative poison and can cross the placenta, concentrating in the fetal brain (Mansour, et. al., 1973). Mercury is also excreted into milk in both organic and inorganic form (Mansour, et. al., 1973). Fluoride is known to be excreted by the lactating breast as well (Welt and Blythe, 1970).

The toxicity of selenium to man depends on its chemical form and is suspected as a possible human teratogen (Robertson, 1970). Selenium has also been reported to protect against arsenic and cadmium-induced teratogenicity (Holmberg and Ferm, 1969).

Lead is known to accumulate in man (Emmerson, 1968), as are cadmium (Friberg, et. al., 1968), arsenic (Harvey, 1970) and mercury (Friberg and Vostal, 1971).

Phytotoxicity is difficult to generalize because, in addition to the normal variables in a plant's response to chemical exposure (e.g., humidity, soil pH, temperature), there is a differential sensitivity in species. Ragweed grows well in soil with high zinc concentrations

(Hemphill, 1972). The toxic effect of cadmium is greater for radishes than for lettuce (John, et. al., 1972). Corn is sensitive to iodine concentrations of 8 µg/g in soil, while lettuce tolerates 160 µg/g (Hemphill, 1972). In many cases, however, metal concentrations in plant parts show poor correlation with soil concentrations of the elements (Shacklette, et. al., 1972). Toxicity from the ingestion of contaminated vegetation in man is a lesser problem than in grazing animals because of the limited food source of the latter. High soil or plant levels of molybdenum or selenium can result in molybdenosis, a copper deficiency, (Hemphill, 1972).

The magnitude of trace element pollution threat remains a subject of controversy. Schroeder (1971) considers atmospheric cadmium, lead, nickel and mercury as major public health hazards. Lee and Von Lehmden (1973) include in this list also vanadium. Woolrich (1973) contends that other than occupational exposure to Be, Sb, Bi, Sn, Cd, Pb and Hg, some trace elements in the air are not threatening public health. Stern (1974) agrees with Woolrich's views.

2.2.3. Organic Effluents

On the basis of modelling reductions, Kilpatrick, et. al., (1980), suggested that the trace and minor elemental components of coal gasification effluents may be of secondary importance to the organic components in terms of health and ecological effects. Alkyl hydrocarbons and simple aromatics are regarded primarily as irritants while polynuclear aromatics (PNA's) are probably mutagenic,

carcinogenic, teratogenic, and co-carcinogenic, while nitrosoamines are probably mutagenic, carcinogenic, and teratogenic (Torrey, 1978). Two and three-ringed PNA's are believed to be less hazardous than four and five-ringed PNA's (Deutsch, 1981). One of the primary suspected environmental carcinogens associated with coal is benzo(a)pyrene, a five-ringed condensed system which has been used as an exposure indicator to PNA carcinogens (Torrey, 1978).

Phenols are toxic to most organisms and may be carginogenic (Tarr and Damme, 1978). Phenols, along with sulfur and nitrogen compounds, are a problem as odorants.

Potentially hazardous organic compounds found in effluents from the Research Triangle Institute fixed-bed gasifier and/or the Morgantown Energy Research Centre fixed-bed gasifier included methyl mercaptan, ethanethiol , benzene, toluene, ethylbenzene, biphenyl, indane, xylene, phenols, cresols, xylenols, naphthalene, acenaphthene, anthracene, phenanthrene, pyrene, fluorine, fluoranthene, pyridine, dibenzofuran, and thiophene (Cleland, et. al., 1978; Gangwall, et. al., 1979). Organic compounds of environmental concern found in the product gas of the Ft. Snelling Wellman-Galusha fixed-bed gasifier included polychlorinated biphenyls, benzo(a)anthracene, benzo(b)fluoranthene, biphenyl,7,12-dimethylbenzo(a)anthracene, benzo(c)phenanthrene, benzo(a)pyrene, 3-methylcholanthrene, dibenzo(a,h)anthracene, dinitrotoluene, dinitrocresol, and dihydroacridine (Kilpatrick, et. al., 1980).

2.2.4. Sulfur Compounds, Ammonia, and Cyanides

Hydrogen sulfide and hydrogen cyanide are highly toxic gases. At normal environmental levels, however, H_2S is of primary importance as an odorant, e.g., used to ensure safe distribution of natural gas. Additional potential atmospheric emissions of sulfur are in the form of SO_2, thiophene, COS, CS_2 and other reduced sulfur compounds. Many of the reduced sulfur compounds are potentially toxic and odorous.

Ammonia is important as an irritant and an odorant. Cyanide is toxic to aquatic life at low concentrations and inhibits biological treatment of waste water.

3. EFFLUENT PRODUCTION IN DIFFERENT GASIFICATION SYSTEMS

3.1. Types of Gasifiers

Gasifiers can be divided into four types: fluidized-bed, fixed-bed, entrained flow and molten media. A brief description of gasification processes utilizing the first three categories is given in Table 3.1.

The raw product gas quality depends on various process parameters, such as gas residence time, coal heat-up rate, temperature and gas/solid mixing. Temperature in general is the major factor, i.e., a high temperature yields lower amounts of by-product hydrocarbon materials.

Fluidized-bed gasifiers operate in a non-slagging mode and the hot product gas typically leaves from the top of the fluidized-bed, contacting fresh and partially consumed coal. The hot gases extract large amounts of volatile material from the solids. The gas temperatures however are not high enough to completely destroy this material and consequently it exits with the product gas (Schlinger and Richter, 1980).

Fixed-bed gasifiers operate in a countercurrent manner either in a slagging or non-slagging mode. In this type of gasifier the hot gases also contact char and fresh coal, extracting various organic

Table 3.1. DESCRIPTIONS OF NINE WELL-KNOWN GASIFICATION SYSTEMS

The HYGAS process uses a multi-stage fluidized-bed gasifier. There are three or four versions of the process, differing in the way in which heat is supplied to the final stage. One version is oxygen-blown. The maximum temperature developed is about 1000°C. The operating pressure is 8.00 - 8.10 MPa. Dry ash is produced.

The WINKLER gasifier is a fluidized-bed type and may be oxygen or air-blown. The maximum temperature achieved is 800 - 1000°C. The gasifier operates at just above atmospheric pressure. Dry ash is produced. The exit gas temperature is 800 - 1000°C.

The SYNTHANE gasifier is a fluidized-bed, oxygen or air-blown unit operating at a maximum temperature of 1000°C. The operating pressure is about 6.9 MPa. The feed carbon is not completely gasified and a residual char is produced. The exit gas temperature may be as high as 760°C.

The CO_2 ACCEPTOR process uses a fluidized-bed gasifier operating at a maximum temperature of 1000°C. Dolomite is heated to release CO_2. The hot acceptor is then fed to the gasifier where it provides heat for the endothermic reactions. Additional heat is released when the acceptor reacts with CO_2 formed in the gasifier. The operating pressure is about 1.0 MPa. A char is produced.

The LURGI gasifier has a fixed-bed and may be air-blown, nonslagging; oxygen-blown, nonslagging; or oxygen-blown, slagging. Maximum temperatures are between 1000°C and 1400°C. Modern units operate at 2.4 - 3.1 MPa. The exit gas temperature is typically 400 - 600°C.

The WELLMAN-GALUSHA fixed-bed gasifier is an air-blown unit operating at about 1300°C and just above atmospheric pressure. Dry ash is produced. The exit gas temperature is about 650°C.

The BI-GAS entrained flow gasifier is oxygen-blown and operates at 1500 - 1650°C and 3.5 - 10.3 MPa. Slag is produced.

The KOPPERS-TOTZEK entrained flow gasifier is oxygen-blown and operates at 1900°C and just above atmospheric pressure. Slag and entrained ash are produced. The exit gas temperature is about 1500°C.

The TEXACO entrained flow gasifier is oxygen-blown and operates at temperatures sufficient to cause slagging. Operating pressures are 2.1 - 8.3 MPa.

materials. Again, the temperature in the zones containing char and fresh coal are not high enough and the residence times are too short to allow for destruction of much of this material (Schlinger and Richter, 1980). Typically, therefore, fluidized-bed gasifiers (i.e., Synthane) and fixed-bed gasifiers (i.e., Lurgi) yield an extremely dirty process condensate.

The CO_2-acceptor process, however, which also operates on the fluidized-bed principle, produces virtually no hydrocarbon byproducts. This low hydrocarbon yield is a direct result of the coal injection into the hot zone of the gasifier, the extended gas residence time and increased gas/solids contact between the product gases and the reactive acceptor and char (Massey, et. al., 1976).

Entrained flow gasifiers use a concurrent oxygen and coal flow, and their higher operating temperatures destroy most of the hydrocarbon byproducts. The Koppers-Totzek entrained gasifier produces virtually no tars, oils or phenols. The high operating temperatures in this gasifier also result in coal nitrogen being converted to free nitrogen rather than ammonia (Probstein and Gold, 1978), which is the fate of much of the coal nitrogen in fixed-bed and fluidized-bed gasifiers.

3.2. Effluent Streams

Different coal gasification processes may produce significantly different effluent streams. Some process effluent streams are specific

to the gasification process, while others are similar in all coal utilization plants. Coal pile runoff, coal preparation runoff and wet-scrubber dust collector effluents, are sources which contain suspended fines, sulfur compounds, and heavy metals. These waste streams are common to both coal gasification plants and coal-fired generating plants.

Liquids from the gas cooling and from the waste heat boilers normally are used as a quench water in the tar separator prior to treatment. The condensate streams from pressurized gasifiers have high dissolved gas concentrations, which flash off when these streams are depressurized. Besides some H_2S which is present as both dissolved H_2S and HS^-, the most common ionic species present are NH_4^+ and HCO_3^- (Probstein and Gold, 1978). The latter two species result from dissolved ammonia and carbon dioxide. The absorption of HCN depends on the pH, and reaches its optimum at or above pH 9.3. Dissolved H_2S and CO_2 therefore tend to decrease the scrubbing efficiency for HCN, while dissolved NH_3 increases the efficiency (Nakles, 1978).

Sulfur plant recirculation water purge and discharge depend on the reclamation system used. Discharges from the Claus process are mainly oils, however, liquid wastes from the Stretford process include anthraquinone disulfonate, metavanadate, citrate, thiosulfate, thiocyanate and sodium salts. The Stretford process removes H_2S selectively, but CO_2 and other sulfur species exit in the off-gas (Intercontinental Engineering, et. al., 1976).

The purge water from the tar separation unit contains ammonia, phenols, and tars as well as reduced sulfur compounds. If the phenol concentration in the process condensate is high, phenol may be removed. Tars and oils separated from the condensate could be disposed of in various ways. The tars and heavy oils could be reinjected into the gasifier as proposed by Lurgi (Intercontinental Engineering, et. al., 1976).

For economic and other reasons many gasification plants are seriously considering recycling all process water. In a Lurgi process designed for zero water effluents, all potential contaminants that can be carried by the water are retained at the plant site in the form of solids. Approximately 80 percent of the total water make-up comes from the water supply source and only about 5 percent of the total water consumed leaves the plant as part of the wet ash and in the by-product ammonia solution (Rickles and Whitenight, 1980). Because no process water is released, water treatment methods necessarily relate to purifying water to process quality. Residual ammonia remains after by-product ammonia has been removed from the gas liquor treatment. The proposed use of sour water strippers to recover ammonia from process streams could cause pollution problems. Impurities such as chlorine, oil, phenols, mercaptans, cyanides, thiocyanates, and polysulfides can affect stripper capacity. The source of phenols in the water, like ammonia is from the gas liquor treatment system. Other aqueous pollutants that are to be treated by the biological treatment system are BOD_5 and suspended solids. The BOD_5 concentration which is often 2500 mg/L is reduced to 75 mg/L. Suspended solids which are negligible in

the inlet stream increase about 5 mg/L. The effluent stream from the biological treatment system (effluent water treatment) is sent to the cooling tower sump.

Other sources of aqueous pollution such as the chemicals used for regenerating the demineralizers, often can end up in the ash quench and removal section and ultimately be returned to the mine. The resulting slurry, however, still may contain leachable materials. Some solid materials and soil inorganic compounds may also enter the effluent water stream from the sulfur recovery process through leakage. Although quantities are small, disposal may present problems.

3.3. Solid Waste Sources

There are several sources of solid wastes from coal gasification facilities. The major source is the gasifier. The composition and quantity of this waste is largely dependent on the coal that enters the gasifier vessel. The elemental composition of gasifier ash may be quite different than bottom ash from the coal combustor. Due to chemical as well as possible physical differences, gasifier ashes may differ in leachability from coal combustor bottom ashes. Other solid waste sources are given in Table 3.2. These solids may contain significant amounts of leachable heavy metals and organics which could contaminate the environment if not treated and disposed of properly. Gasifier dry ash would be much more susceptible to leaching than gasifier slag. Ash leachability is an important factor in the transfer process of ash trace elements to the environment.

Table 3.2. SOLID WASTES FROM COAL GASIFICATION FACILITIES(1)
(Hittman Associates Inc., 1975)

Source	Quantity (Mg/d)
Quenched ash from gasifiers	1550
Steam generator bottom ash	38
Steam generator fly ash	114
Intake water clarifier sludge	2
Bio-treatment sludge	4
Miscellaneous fly ash	150
Spent catalysts	2

(1) Plant Size 7.08×10^6 m^3/d

3.4. Airborne Emissions

Shroeder (1973) has identified 27 trace elements which may be airborne. Many of these elements are present naturally in windblown dust, particularly; Al, Ba, Si, Sr, and Ti (Schroeder, 1974). Elements which are or may be emitted into the atmosphere from coal combustion are Ni, As, Ti, Sb, Be, V, F, Pb, B, Hg, Ge, Ga, Sn, W, Ag, Se, Zr, Yt, Bi, Ba, Mn, Co, Cu, Zn, U, Cd, Te and Tl (Torrey, 1978; Schroeder, 1973). On the basis of their volatilities, the major elements present in the flue gas and possibly raw gasifier product gas are probably As, Cd, Hg, Pb, and Te (Torrey, 1978). Many elements such as Ag, Al, B, Ba, Co, Cr, Cu, Fe, Ge, Mn, Pb, Se, Sn, Ti, W, and Zn are present mainly in the bottom ash (Torrey, 1978).

Some of the inorganic constitutents in coal may be vaporized and exit with the product gas (Kilpatrick, et. al. 1980). Nonabsorbed gas phase elements may possibly be present as metal carbonyls ($Fe(CO)_5$, and $Ni(CO)_4$), hydrides (arsine, stibine), organometallics, organic salts, inorganic salts, oxides, or in elemental form. The volatility of the element will depend upon the species present.

3.5. Analytical Programs for Coal Gasification Effluents

Many of the American research efforts have approached the environmental assessment of coal gasification effluents by extensive, and in some cases exhaustive, sampling, quantitation and identification programs, often on large process development or pilot plant units.

Due to a more strict regulatory approach which increasingly demands identification and quantification of trace amounts of specific compounds, there exist an inherent trend to favour voluminous data production. Many organizations therefore are expending much of their research effort in developing and validating state of the art methodologies for the exhaustive analysis of coal gasification products and by-products.

Summaries of some research programs on gasification effluents are presented here.

3.5.1. The Radian Corporation Monitoring of the CO_2 Acceptor Pilot Plant (Massey et. al., 1978a)

Analysis were performed on raw and preheated lignite; raw, calcined, and spent acceptor; char; gasifier and regenerator cyclone solids; and gasifier quench water solids. These effluents were analysed for:

(1) Major elements: C, H, N, O, S, Al, Ca, Si, Fe, Li, Mg, Na, Ti, K

(2) Trace elements: As, Be, Cd, Cu, Cr, Pb, Hg, Sb, Mn, Ni, Se, Tl, V, Zn.

Liquids, including the gasifier and regenerator quench water, and recycle water from the regenerator off-gas scrubber, were analysed for:

(1) Major characteristics: TDS, TSS, TS, VDS, VSS, TVS, TOC, COD, NH_3-N, pH, total hardness, specific conductance and phenols.

(2) Anions: U-, F-, SO_4^{2-}, SO_3^{2-}, NO_3^-, PO_4^{3-}, CN-, SCN-

(3) Elements: Al, As, Be, Ca, Cd, Cu, Cr, Fe, Hg, K, Li, Mg, Mn, Mo, Na, Ni, Pb, S, Sb, Se, Si, Ti, Tl, V, Zn.

Gases were analysed for:

HCN, H_2S, CO, CO_2, SO_x, NO_x, COS, CS_2, HCl, HF, NH_3 and trace elements: As, Sb, Be, Cd, Cu, Cr, Pb, Hg, Mn, Mo, Ni, Se, Tl, V.

3.5.2. The Research Triangle Institute Fixed-Bed Gasifier (Cleland, et. al., 1978; Gangwal, et. al., 1979)

Particulates were removed from the raw product gas from the gasifier by a particulate trap which was being maintained at exit gas temperature to prevent condensation of tars and oils. Tar and water were removed in a water cooled trap. Gas samples were analysed for: H_2, CO_2, CO, N_2, O_2, CH_4, C_2H_6, C_2H_4, H_2S and COS, as well as C_1-C_6 hydrocarbons, C_6H_6, C_7H_8 and C_8H_{10}. The gases were also analysed for COS, CH_3SH, C_2H_5SH, $(CH_3)_2S$, CS_2, and thiophenes. Solvent extractions were used to

separate tars into organic acids, organic bases, nonpolar neutrals, medium polar neutrals (PNA's), polar neutrals, and insolubles. The acid, base and PNA fractions were analysed by GC/MS. The water soluble organics, mainly, phenols, cresols, and xylenols, were anlaysed by HPLC.

Absorbent traps, containing XAD-2 and charcoal were used to trap volatile organics and some gas phase trace metals.

Most of the analytical emphasis was placed on identifying hazardous compounds, primarily organics, in the gasifier effluent.

3.5.3. The North Carolina State University Fluidized-Bed Gasifier (Felder, et. al., 1980)

A cyclone is used to remove most of the entrained particulates from the raw product gas. The gas is then quenched in a venturi scrubber, where water soluble and condensible comounds are removed. The condensate may be recycled to the scrubber. The quenched gas passes through a demister and a filter before being vented. Gas samples were taken between the cyclone and scrubber and after the filter.

The coal and char solids were analysed for the trace elements: As, Be, Cd, Cr, Hg, Ni, Pb, Sb, V. The gas was analysed for:

(1) N_2, CO, CO_2, H_2, H_2O, CH_3OH, CH_4, H_2S, COS, CS_2 and mercaptans.

(2) Trace elements: As, Be, Cd, Cr, Hg, Ni, Sb, V.

Waste water was analysed for:

(1) Major elements: C, N, S.

(2) Compounds: ammonia, phenolics, bensinc, toluene, xylene.

(3) Water water parameters: TOC, COD, pH, Cl^-, OCH^-, CN^-, SO_4^{2-}, S^{2-}, SO_3^{2-}, SCN^-.

(4) Trace elements: As, Bc, Cd, Cr, Hg, Ni, Pb, Sb, V.

3.5.4. Environmental Assessment of the Fort Snelling Wellman-Galusha Gasifier (Kilpatrick, et. al., 1980)

An extensive sampling and analytical program for environmental assessment was conducted, and only some selected examples will be discussed here.

The product gases were analysed for: H_2, N_2, O_2, CO, CO_2, H_2S, CS_2, SO_2, COS, CH_3SH, C_2H_5SH, C_2H_5SH, $(CH_3)_2S$; C_1-C_6 hydrocarbons, NH_3, HCN, and trace elements.

Liquids were analysed for: pH, TDS, TSS, SO^{2-}, SO_4^{2-}, NO_3^-, NO_2^-, PO_4^{3-}, CN^-, NH_3, COD, BOD, phenol, Cl-F-, TOC. The liquids were also screened for organics and 72 elements. Gasifier ash, cyclone dust, and the raw lignite were analysed for 72 elements, while the ash and cyclone dust were also analysed for organics. Scrubbers were used to

trap vapor phase trace elements, sulfur gases, metal carbonyls, ammonia and HCN.

3.5.5. The Grand Forks Energy Technology Centre Fixed-Bed Slagging Gasifier (Ellman, et. al., 1977, 1979)

The raw product gases were passed through a spray washer, gas cooler, and a scrubber before sampling. The gases were analysed for H_2, N_2, O_2, CO, CO_2, H_2S, C_2H_6, C_2H_4, C_3H_8, C_3H_6, i-C_4H_{10}, NC_4H_{10} and 20 other hydrocarbons. The gases were also analysed for H_2S, COS, CS_2, SO_2, and thiophene.

Waste water was analysed for pH, TOC, TIC, COD, TSS, TDS, alkalinity, phenol; o-, m- and p-cresol, NH_3, CN^-, S^{2-}, total sulfur, conductivity, specific gravity, trace elements, and suspended tar.

Tar and oils were analysed for C, N, O, H, S, boiling point distribution and heating value.

3.5.6. Thermochemical Institute, Brigham Young University Entrained Flow Gasifier (Hansen, et. al., 1980)

The research program looked at the effect of operational parameters on the amount and type of effluents. Analysis was performed on the original coal, the product gas, the bottom ash and slag, the srubber water and flash gases, and the scrubber water particulates. The operating parameters varied were the coal type, coal feed rate, reactor pressure, oxygen/coal ratio, and steam/coal ratio.

The product gases were sampled for particulates and analysed for SO_2, RS_2, NH_3, H_2S and HCN. The scrubber water was analysed for Na^+, NH_4^+, F^-, Cl^-, NO_2^-, NO_3^-, Br^-, SO_3^{2-}, SO_4^{2-}, and HCO_3^-.

4. EXPERIMENTAL

4.1. Gasifier Description

The gasifier is a small air-blown, non-slagging unit, equipped with a continuous feed system. Ash removal is not continuous and the accumulated ash is removed at the end of each run.

The reactor is a tubular vessel and consists of a 102 mm O.D. -51 mm I.D. Hastelloy C-276 cylinder with an overall length of 1525 mm. The top most 305 mm are reduced to 32 mm I.D. The raw gas leaves the reactor 152 mm below the top (Figure 4.1). The coal is introduced via the top and is supported on a perforated disk during gasification. The disk, which is supported by a stand pipe, can be removed via the bottom closure. The disk is removed after each run for cleaning and ash removal.

The coal is introduced into the reactor in discrete quantities via a presurized hopper equipped with a modified 25 mm WK-dynaseal ball valve. The ball is equipped with an insert, dividing the full bore opening into two cups. The valve delivers 16 g of coal to the reactor with each 180 degree rotation.

The reactor is heated with an external 6 kW electric furnace (Lindberg Model 54557). Air and steam are introduced into the reactor above the bottom closure.

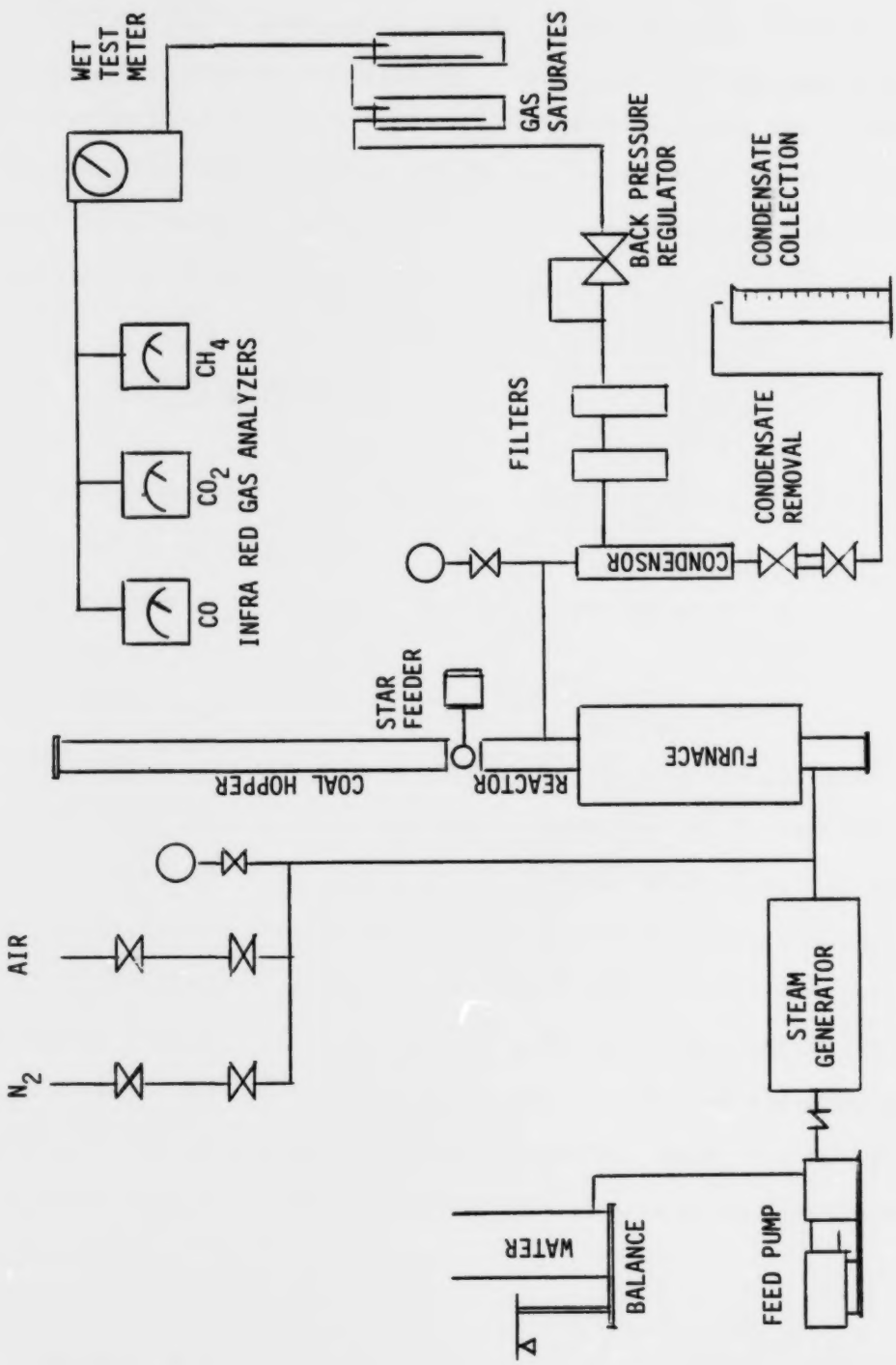


Figure 4.1. EXPERIMENTAL SETUP

The raw gas is quenched in a water cooled condensor, filtered and reduced to atmospheric pressure. The condensor is equipped with a lock system to allow periodic removal of condensate. The gas volume is measured with a wet test meter and the gas is then directed to a manifold connected to three infra-red gas analysers. These analysers measure the concentration of CO, CO_2 and CH_4 in the gas.

4.2. Experimental Procedure

The experimental conditions are outlined in Table 4.1. The runs are identified by YYZ-XMPa, where X is the reactor pressure, YY is a run sequence number and Z is E or C for Estevan and Coronach coal respectively.

Several preliminary runs were conducted to check the performance of the continuous feed system. The feed system delivered discrete amounts of 16.2 $\pm$ 0.4 g air dried coal under atmospheric conditions. For each run the reactor was pressurized with nitrogen after the desired operating temperature had been reached. Approximately 400 g of coal were then introduced into the reactor by 25 continuous valve rotations of 180 degrees each. The air and steam flows were then started and additional amounts of coal were added at regular intervals. These intervals were calculated from the carbon consumption rate as determined from the gas analysis.

Problems were encountered with plugging of the reactor below the hopper valve. Variations in cup volume and valve rotational speed did

Table 4.1. EXPERIMENTAL CONDITIONS USED DURING THE GASIFICATION OF ESTEVAN AND CORONACH LIGNITES

Reactor Pressure 2 MPa, Airflow Rate 7.9 L/min(1)

Coal Type	Coronach			Estevan		
Steam Flow Rate g/min	4.7	8.3	16.2	4.2	8.4	16.2
Run Sequence	25C	21C	23C	28E	22E	24E

Reactor Pressure 4 MPa, Airflow Rate 7.0 L/min

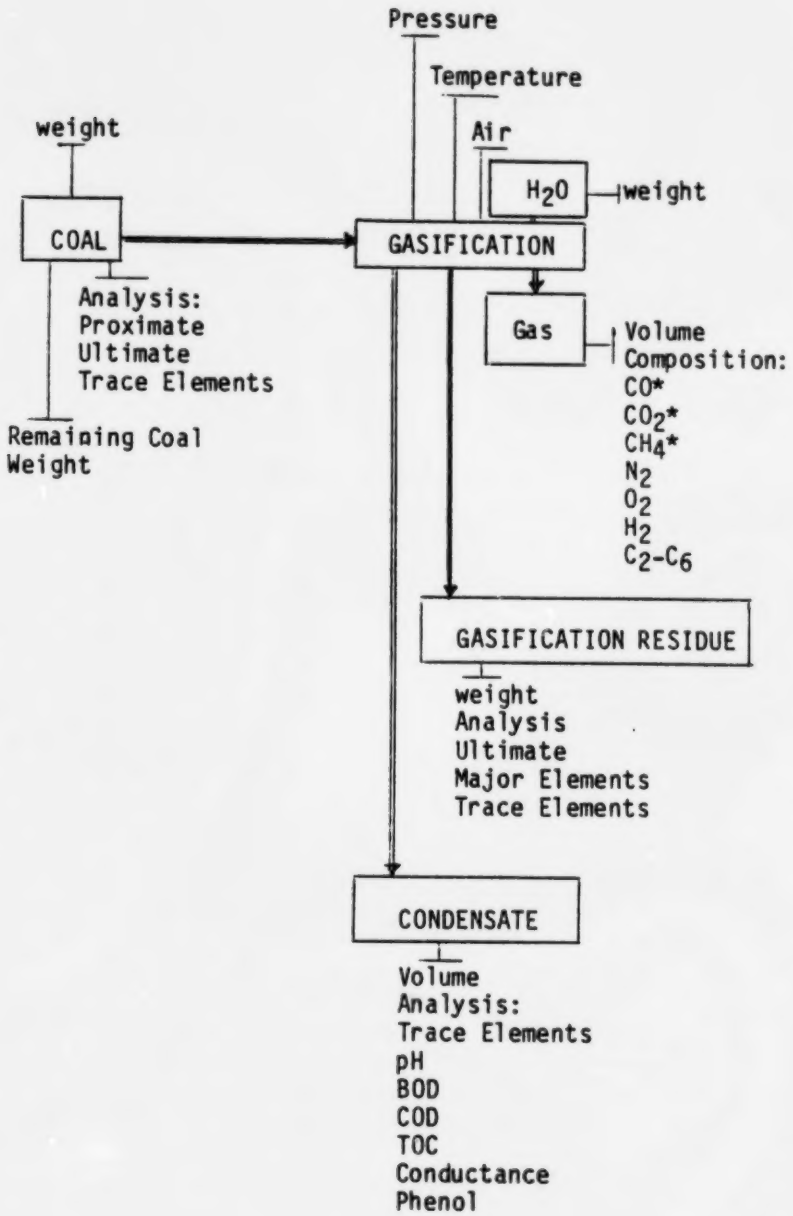
Coal Type	Coronach			Estevan		
Steam Flow Rate g/min	4.1	8.2	14.8	4.1	8.2	16.0
Run Sequence	26C	17C	19C	27E	18E	20E

(1)at 15°C and 101.325 kPa

not rectify the problem. This plugging tendency is believed to be caused by condensation of unreacted steam and volatile matter in the cooler top section of the reactor. Attempts to heat this section externally with heat tape were not successful. The shape of the top closure, which also serves as a reactor support, interferes with proper application of the heat tape. The duration of the gasification runs varied from 92 to 195 minutes. Although this is shorter than the original anticipated duration of 240 to 300 minutes, sufficient quantity of residue and condensate was generated for the environmental analysis. The amount of tar produced was too small for trace analysis, and even at the extended reaction times the yield would have been insufficient for extensive analysis. The type of analysis performed on the feedstocks and effluents are given in Figure 4.2.

The temperature was measured by a single thermocouple in a well protruding through the carbon steel support disk into the coal bed. The use of multi thermocouples (up to 5) in a single well was not successful. The thermocouples required replacement after each run due to their fragile nature, slowing the turn around to three runs in two weeks as compared to eight runs in the same time period. A temperature profile obtained during one of the preliminary runs using a multi-thermocouple well is given in Figure 4.3.

During each run the condensate was periodically removed from the condensor and the volume recorded. The total amount of condensate collected was divided in several parts as required for the various types of analysis. The description of the analytical methods used in the



*I.R. Analysers

Figure 4.2. ANALYSIS PERFORMED ON THE FEEDSTOCK AND EFFLUENTS FROM GASIFICATION RUNS

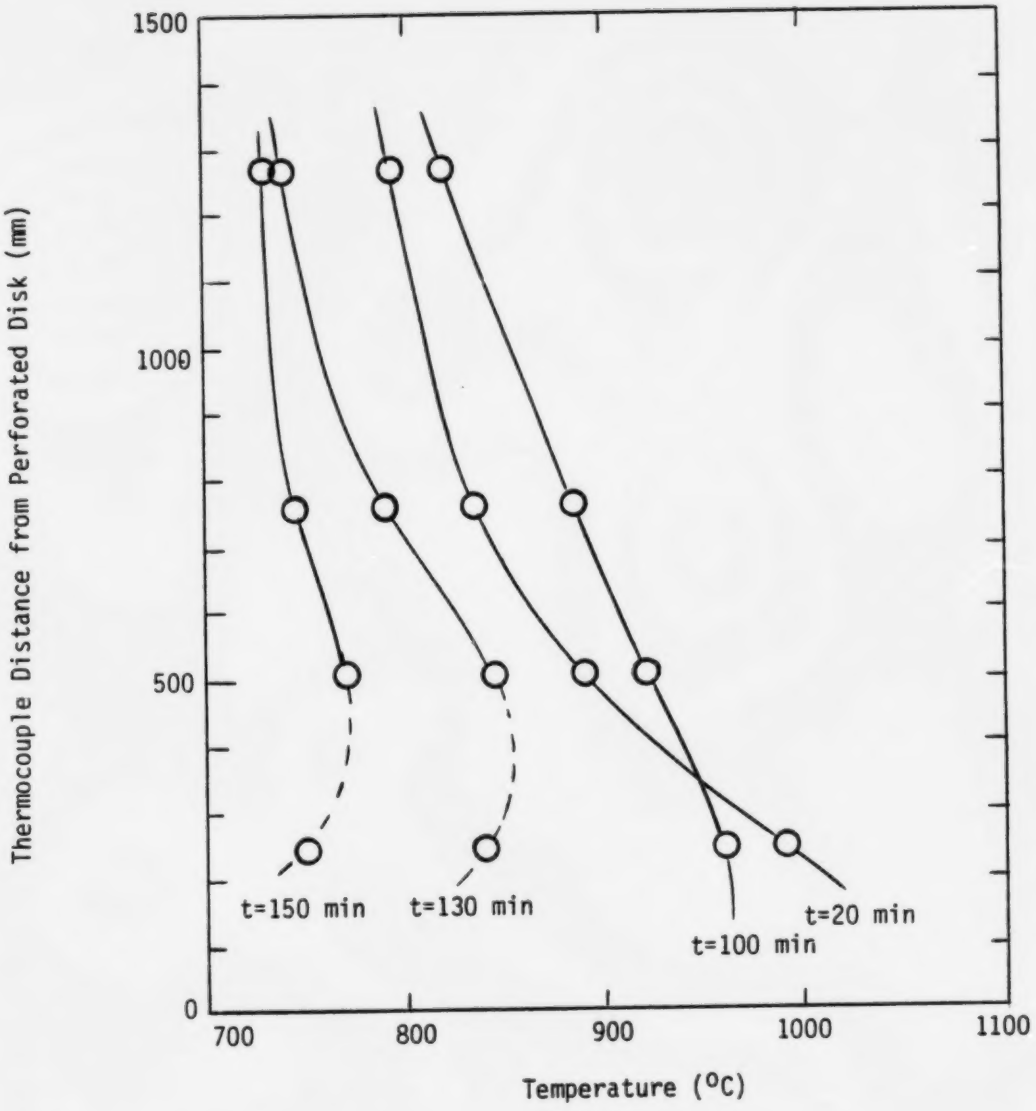


Figure 4.3. TEMPERATURE PROFILES MEASURED AT SEVERAL DISTANCES FROM THE PERFORATED DISK AT DIFFERENT TIME INTERVALS.

determination of the physical water quality parameters and the trace elements is given in Appendix B. The methods used in the determination of the major and trace elements in the coal feedstock and char/ash residues is given in Appendix C.

The runs reached steady state conditions within 15 minutes as indicated in gas composition profile given in Figure 4.4. The small fluctuations observed in the methane concentration resulted from increased devolatilization when fresh coal is introduced into the reactor. The gas composition was monitored with three on-line infra red gas analysers. The analyser reading was taken at two minute intervals and these readings were used to calculate the carbon consumption over this interval. Coal was added from the hopper to keep the quantity in the reactor constant.

The runs were terminated when variations in the CH_4 concentration were no longer observed with each addition of fresh coal. The lack of concentration variations indicates plugging below the coal hopper, and no additional coal can be added to the bed in the reactor. The runs were continued until the CO concentration equalled the CO_2 concentration in the off-gas. This point clearly indicated breakthrough of oxygen and, therefore, completion of the run.

The residual char/ash was removed on the next working day after overnight cooldown of the reactor.

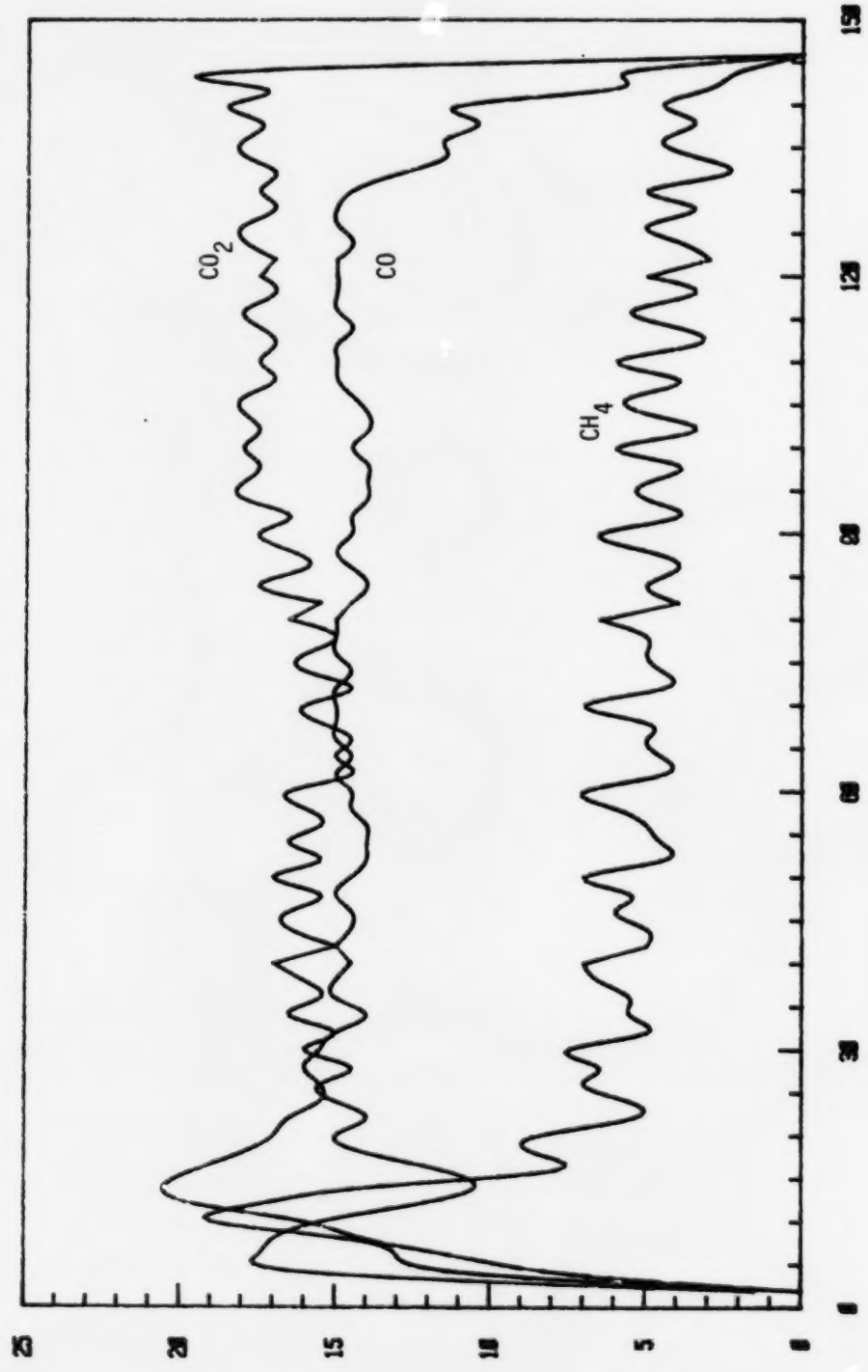


Figure 4.4. GAS COMPOSITION PROFILE FOR RUN 22E-2MPa

5. RESULTS

The condensate analysis are given in Appendix B. Tables B.2 and B.3 contain the trace element analysis for the condensates collected during the gasification of Coronach and Estevan lignites respectively. Because the concentration of several elements is below the detection limit, the concentrations are those as determined and have not been corrected for dilution prior to analysis. Because of the many analysis involved, the condensate samples were diluted by 2 to 3.3 times to obtain the required total volume for all analysis. The corrected values will be used in the discussion with other parameters. Corrected parameters for Biological Oxygen Demand (BOD), Total Organic Carbon (TOC), Chemical Oxygen Demand (COD) and phenols are listed in Table B.4. The pH and conductivity values were measured on the original sample before dilution.

The results of the gasification residue analysis are listed in Appendix C. Here Tables C.1 and C.2 list the concentrations for the gasification residues from Coronach and Estevan lignites respectively. Table C.3 lists the concentrations of major and trace elements for both lignite feedstocks.

6. DISCUSSION

6.1. Liquid Effluents

6.1.1 Water Quality Criteria; General Policy

At present there exist in Saskatchewan no rigid effluent or receiving water standards, but instead each case of waste disposal will be examined by the Department of the Environment on its own merits from a water quality management point of view. However, guidelines or objectives are necessary to assist in the evaluation of each case and their interpretation is based on field data, the uses of the water body in question and the effects there on, as well as practicability of treatment.

Each substance that may enter a body of water is considered to be a potential pollutant. If the substance is concentrated sufficiently, it can adversely affect one or more uses of the water body, yet if adequately diluted this same substance will be harmless. The concentration of these potential pollutants in water is a function of the amount of polluting substances added and such factors as self purification and dilution. Factors which influence the degree of pollution and which are used to assess the degree of treatment required are in addition to the nature and volume of the polluting waste, the effects of pH, climate, dilution, natural quality and character of the receiving water, mixing, chemical and biological changes, velocity of flow, specific requirements for beneficial uses and other variables.

The following are the basic objectives applicable to all waters receiving effluents from municipal, industrial, agricultural or other discharges (Environment Saskatchewan 1977). These discharges should be:

1) free from substances in concentrations or combinations which are toxic or may be harmful to human, animal or aquatic life;

2) free from substances that will settle to form putrescent or otherwise objectionable sludge deposits, or that will adversely affect aquatic life or water fowl;

3) free from debris, oil, grease, scum or other materials in amounts sufficient to be noticeable in the receiving water;

4) free from colour, odor, turbidity or odor-producing materials that would:
   - adversely affect aquatic life or water fowl;
   - significantly alter the natural color of the receiving water;
   - directly or through interaction among themselves or with chemicals used in water treatment, result in undesirable taste or odor in treated water;

5) free from nutrients in concentrations that create nuisance growths of aquatic weeds or algae in the receiving water.

Specific surface water quality objectives are given in Appendix D. There are many instances where the natural water quality of a lake

or river does not meet some of the suggested limits. In these cases the limits do not apply, but no further deterioration by unlimited or uncontrolled introduction of pollutants is permitted.

6.1.2 Trace Elements

A comparison of the gasification condensates from Coronach and Estevan lignite with gasifier ash sluice water and cyclone dust quench water for the Ft. Snelling fixed bed gasifier is made in Table 6.1. The table shows that the condensates are characteristic of a fixed bed gasification process. The trace element concentrations ranges are similar with exception of chromium (Cr) and copper (Cu). The values of 0.22 and 0.48 mg/L for copper in runs 28E-2MPa and 27E-4MPa are more than an order of magnitude higher than the copper concentrations in the remaining samples. Chromium concentrations in three runs (17C-4MPa, 28E-2MPa and 27E-4MPa) are at least an order of magnitude above concentrations for the other tests. Both runs 28E-2MPa and 27E-4MPa were conducted at low steam to air ratio's, thus yielding low condensate volumes.

With regard to the treatment of waste waters, the amount of pollution load allowed to be discharged, in the receiving water, in most cases will be a given number of kilograms of substance per day rather than a maximum allowable concentration (in mg/L) of the pollutant in the effluent.

Since trace elements concentrations are virtually unaffected by waste treatment, their loading could govern the allowable waste discharge.

Table 6.1. COMPARISON OF THE TRACE ELEMENT CONCENTRATIONS IN GASIFIER CONDENSATE WITH OTHER FIXED BED GASIFICATION FACILITIES

			Ft. Snelling Gasifier (Kilpatrick, et. al., 1980)	
Element	Coronach Range mg/L	Estevan Range mg/L	Gasifier Ash Sluice Water	Cyclone Dust Quench Water
As	0.076 - 0.104	0.058 - 0.104	0.0033	0.12
B	12 - 22	10 - 20	--	--
Ba	0.3 - 0.6	<0.2 - 0.4	0.13	0.57
Be	<0.002 - 0.006	<0.002	--	--
Cd	<0.002 - 0.003	<0.002 - 0.002	<0.002	<0.005
Cl-	--	--	78	34
Co	0.005 - 0.22	<0.002 - 1.15	--	--
Cr	<0.02 - 0.25	<0.02 - 0.14	0.007	<0.005
Cu	0.018 - 0.103	0.046 - 0.480	0.017	0.012
F-	0.53 - 1.45	0.80 - 1.23	0.87	2.0
Fe	--	--	1.2	4.9
Hg	<0.0010	<0.0010	0.0014	0.0004
Mn	0.02 - 0.08	<0.02 - 0.06	0.002	<0.001
Mo	0.48 - 1.32	0.34 - 1.36	--	--
Ni	0.008 - 0.276	0.006 - 0.46	--	--
Pb	0.008 - 0.033	<0.008 - 0.035	0.008	0.099
Sb	0.006 - 0.020	0.014 - 0.076	--	--
Se	0.012 - 0.340	0.004 - 0.060	0.020	0.006
Te	<0.2 - 0.6	<0.2 - 0.4	--	--
Tl	<0.02	<0.02	--	--
U	0.0016- 0.0130	0.0016- 0.0024	--	--
V	<0.002 - 0.010	<0.002 - 0.002	--	--
Zn	<0.002 - 0.148	<0.002 - 0.154	0.044	0.035

Since the most stringent requirements are placed on water suitable for human consumption, a comparison is made between the condensates and drinking water objectives. Table 6.2 compares the concentration range of potential toxic and other trace elements with the Canadian Municipal Drinking Water Objectives, the United States National Interim Primary Drinking Water Standards and Proposed Secondary Drinking Water Regulations. The above comparison does not indicate that the waste waters are fit for consumption, but will yield an appreciation for the level of dilution that is required to bring trace element concentrations to acceptable levels.

For all elements listed only arsenic (As), boron (B) and chromium (Cr) exceed the objectives. All other trace element concentrations are well below the allowable levels. The chromium concentrations are exceeded in samples 17C-4MPa, 28E-2MPa and 27E-4MPa, all using low steam to air ratios. Arsenic and boron concentrations are exceeded in all samples. The boron levels in both Coronach and Estevan lignite are high 276 µg/g and 220 µg/g respectively. The boron levels correspond to the upper concentration range reported for North American coals by Ruch et. al. (1974). The arsenic levels are at the low end of the scale. When the potential toxicity of As, B and Cr is being considered (Table 6.3), the effects of chromium may be more harmful to than the effects of arsenic. Boron is harmful to boron sensitive plants, and may have a long term effect on health if ingested in large amounts over protracted time. Boron may be beneficial to some aquatic lifeforms (Jones, et. al., 1977).

Table 6.2. COMPARISON OF TRACE ELEMENT CONCENTRATIONS[1] IN GASIFICATION CONDENSATES WITH CANADIAN AND US DRINKING WATER OBJECTIVES

Element	Concentration Range in Gasification Condensate		Drinking Water Objectives			
			Canadian		United States	
	Coronach	Estevan	General[2]	CHTR[3]	NIPDWS[4]	PNSDWR[5]
Ag	--	--		0.05	0.05	
As	0.076 - 0.104	0.058 - 0.104		0.05	0.05	
B	12 - 22	10 - 20		5.0		
Ba	0.3 - 0.6	<0.2 - 0.4		1.0	1.0	
Cd	<0.002 - 0.003	<0.002 - 0.002		0.005	0.01	
Cl	--	--	250			250
Cr	<0.02 - 0.25	<0.02 - 0.14		0.05	0.05	
Cu	0.018 - 0.103	0.046 - 0.48	1.0			1.0
F	0.53 - 1.45	0.80 - 1.23	1.5		1.8	
Fe	--	--	0.3			0.3
Hg	<0.0010	<0.0010		0.001	0.002	
Mn	0.02 - 0.08	<0.02 - 0.06	0.05			0.05
Pb	0.008 - 0.033	<0.008 - 0.035		0.05	0.05	
Se	0.012 - 0.340	0.004 - 0.060		0.01	0.01	
U	0.0016 - 0.0130	0.0016 - 0.0024		0.02		
Zn	<0.002 - 0.148	<0.002 - 0.154	5.0			5.0
pH			7.0-9.5			6.5-8.5

(1) All concentrations are in mg/L except pH.
(2) General chemical parameters, maximum desirable concentration.
(3) CHTR = Chemical - Health and Toxicity Related parameters, maximum acceptable concentration.
(4) NIPDWS = National Interim Primary Drinking Water Standard, Federal register (31/3/77).
(5) PNSDWR = Proposed National Secondary Drinking Water Regulations, Federal register (31/3/77).

Table 6.3. POTENTIAL TOXICITY OF TRACE ELEMENTS FROM COAL TECHNOLOGIES (Jones, et. al., 1977)

Element	Plant	Animal	Aquatic	Comments
As	Low	Low	Low	
B	High	Medium	Low*	Known enough on toxicity for terrestial ecosystems; in some instances may be beneficial.
Be	Medium	High	High*	
Bi	Medium	Low	Low*	
Cd	High	High	High	
Co	High	Medium	High	
Cr	High	Medium	Medium	Cr^{6+} very toxic--need to know speciation.
Cu	High	Medium	Low	Complexion in soil reduces toxicity; in some instances it may be beneficial.
F	High	High	Low	
Hg	Medium	High*	High	Enriched in plants, toxicity in food cycle.
Mn	Low	Low	Low	Potential for net beneficial effects.
Mo	Low	Medium	Low	High enrichment in plants--beneficial or adverse effects.
Ni	High	High	Medium	Very mobile in plants.
Pb	Low	Medium	Medium	
Sb	Medium	High*	Low*	
Se	Medium	High	Low*	Interacts with other trace elements, e.g. Ni, Hg.
Sn	Low	Low	Low	
Ti	Low	Low*	Medium*	
Tl	High	High	Medium*	
V	High	Low*	Medium*	
W	Medium	Medium*	Low*	Very mobile in plants.
Zn	Low	Medium	Medium	Potential for net beneficial effects.

* Uncertain. However, certain metals such as Se can become soluble under alkaline conditions (present in western coal areas). Se has been observed to kill fish in cooling reservoirs receiving discharges from fly ash settling ponds. Some investigators also believe that the toxicity of arsenic (As) and lead (Pb) is greater under certain conditions than those given in this table.

Waste water parameters for the Kopper-Tozek gasification process are listed for comparison in Table 6.4. Surface Water Objectives for Saskatchewan are listed in Appendix D.

6.1.3 Physical Parameters

With regard to treatment of waste waters the actual amount of pollution load discharged, and its effect on the receiving water is important. In most cases the allowable waste discharge will be a given number of kilograms of substance per day rather than a maximum allowable concentration in mg/L in the effluent. It should be recognised that water courses primarily containing effluent will not meet the surface water quality objective even with secondary treatment. Although the Department of Environment has set guidelines for sewage waste treatment, it should be noted that these values are based primarily on experience with municipal sewage treatment and therefore some values may have to be altered when applied to industrial waste treatment.

Mott (1980) assessed the treatability and reuse options for waste waters from fossil fuel (and biomass) conversion processes (Table 6.5). Both similarities and significant differences were found in the requirements for individual energy technologies. While waste water treatment was not found to be a technical barrier to any technology, Mott (1980) determined that waste water treatment could represent a potential economic hinderance to systems designed to meet assumed stringent future effluent standards with once-through water use. Typical aqueous effluent parameter ranges for different gasification processes are given in Table 6.6.

Table 6.4. KOPPER-TOTZEK GASIFICATION WATER ANALYSIS: KUTAHYA, TURKEY (Braunstein, et. al., 1977)

Constituent	Amount in mg/L at Sample Location(1)				
	I	II	III	IV	V
CaO	78	101	78	135	179
MgO	97	161	194	145	113
Na	17.5	17.5	17.5	17.5	17.5
K	5.6	8.8	10.0	8.0	8.0
Fe	0.05	0.22	1.95	0.20	0.64
Zn	0.01	0.03	0.02	0.02	0.02
Cu	0.01	0.01	0.01	0.01	0.06
NH_4^+	0.32	157	184	137	122
NO_2^-	0.02	0.13	4.47	0.24	4.37
NO_3^-	58.2	3.32	13.7	24.7	22.9
PO_4^{3-} (total)	1.98	0.81	1.21	0.81	2.70
Cl^-	18	85	96	57	46
SO_4^{2-}	42	216	155	255	109
CN^-	0.26	0.52	12.5	1.4	14.0
COD	14	8	128	16	63
Suspended Solids	14	4612	5084	3072	50
pH(2)	8.8	8.8	8.9	8.8	8.9

(1) I = Cooling water to slag quench tank.
II = Water from slag quench tank.
III = Wash water from gas cooler.
IV = Total water to clarifier.
V = Water out of clarifier.

(2) in pH units.

Table 6.5. POTENTIAL TREATMENT GOALS FOR DISCHARGED WASTES (Mott, 1980)

Constituent	Feed Range mg/L	Goal Range mg/L	Remarks
Organics			
Phenols	50 - 10000	0.05 - 0.5	May be set lower in the future. Detection uncertain since all phenols are lumped together in the calorimeter test.
Carboxylic Acids	50 - 2000	100	Standard may be set in BOD or COD specification. Odour at acid pH.
Organic Bases	10 - 600	0.1 - 10	Odour level a problem. Likely to be set in COD limit.
Polycyclic Bases	0.01 - 1	10^{-5} - 10^{-3}	Largely an unknown.
Polynuclear Aromatics (PNA); Polynuclear Aromatic Hydrocarbons (PAH)	0.01 - 1	10^{-6} - 10^{-3}	Can be detected at pg/L levels by fluorescence. Limits may be set in ng/L range.
Oil and Grease	100 - 20000	1 - 10	Measured in terms of domestic and animal standards. Sheen is likely test.
Organic Sulfur	Varies widely with type of coal and type of conversion process.	0.1 - 10	Difficult to identify; likely to appear in polynuclear aromatics. Odour may be problem.

Table 6.5 (Continued)

Constituent	Feed Range mg/L	Goal Range mg/L	Remarks
Tars	--	--	Decanted. Not a problem since they do not emulsify as do oil and grease.
BOD	100 - 20000	10 - 30	Lower limit of detection is about 3.
COD	200 - 80000	30 - 300	Lower limit of detection is 1-2.
Inorganics			
Ammonia (NH_3) (reported as N)	1000 - 20000	1 - 10	Current typical standard is 10.
Sulfide (S^{2-})	20 - 30000	0.03 - 0.3	Mostly H_2S. Current standard 0.3. Odour problem.
Carbonate (CO_2) (reported as $CaCO_3$)	1500 - 25000	--	
Cyanide (CH^-)	2 - 200	0.02 - 0.2	
COS	? - 1	--	Important in its effects on S limits.
SCN^-	10 - 2000	--	Potential problem in biological treatment.
Physical Parameters			
Total Dissolved Solids (TDS)	1000 - 20000	500 - 5000	Alkaline salts. Does not include ammonia.

Table 6.5. (Continued)

Constituent	Feed Range mg/L	Goal Range mg/L	Remarks
Colour	Often Strong	Undetectable	Associated, at least in part, with polyhydric phenols.
Odour	Often Strong	Insignificant	Associated with substances noted above.
pH	5.5 - 10	6 - 9	

Table 6.6. COMPARISON OF AQUEOUS EFFLUENT COMPOSITION CHARACTERISTICS FOR VARIOUS COAL CONVERSION PROCESSES (Luthy, 1978)

Constituent mg/L	Synthane N. Dakota Lignite	Hygas Montana Lignite	CO_2-Acceptor Glenharold Lignite	Lurgi (Westfield Scotland) Montana Sub-Bituminous
Phenolics	2900 - 4300	1400 - 2000	1.4 - 3.4	6200 - 4200
TOC	5200 - 7000	3400 - 6800	9 - 27	---
NH_3-N	6200 - 6700	1200 - 1900	660 - 1800	2600 - 5600
CH^-	---	<0.003 - 0.105	1.6 - 3.0	2.2 - 3.2
SCN^-	5 - 30	180 - 450	1.1 - 3.0	7.2 - 84
COD	13,000 - 29,000	---	59 - 100	17,000 - 22,000
TDS	---	940 - 4800	800 - 2700	3800 - 9900
TSS	10 - 1800	18,000 - 38,000	710 - 3100	---
pH	7.9 - 9.3	---	8.7 - 8.8	---

Some controversy exists as to which physical parameters are important in assessing the quality of gasification waste waters. Massey, et. al. (1978c) points out that such constituents as hardness and alkalinity, should receive less emphasis than constituents such as phenol, sulfide and TOC. Their rationale is that presumably the pH will be between 6 and 9 pH units, so alkalinity is not important. They also doubt the usefulness of BOD measurements, and indicate that BOD data are not really too useful for design purposes because of dilution requirements and because the bacterial strain will probably be different in a biox facility than in any laboratory setup. Massey et. al., (1978c) maintains that it is better to identify parameters which may be correlated with BOD, i.e. COD, TOC and phenol.

The phenol/TOC ratios seem to be characteristic for the type of gasification process used. The phenol/TOC ratio for our gasifier effluents fall within the 0.77 -1.13 range with an average value of 0.83, comparable to the ratio of 0.82 obtained for the GFETC -fixed bed gasifier (Table 6.7). A comparison of the BOD, COD, TOC and phenol concentrations for Coronach and Estevan gasification condensates are given in Figures 6.1 and 6.2 respectively. The figures show that in general the chemical oxygen demand (COD) exceeds the biochemical oxygen demand (BOD). The COD method is based on the fact that most organic compounds can be oxydized by potassium dichromate under acid condition. The BOD is defined as the quantity of oxygen required under the test conditions by certain organic and water borne substances, but particularly organic matter, to provide for their oxidation mainly by biological means. A sample of water is incubated at 20°C for five days

Table 6.7. PHENOL/TOC RATIO'S FOR VARIOUS COAL CONVERSION PROCESSES(1)

Coal Type	Process	Reactor Type	Phenol/TOC
Lignite	SYNTHANE-PDU	Fluidized Bed	0.27(2)
Lignite	GFETC	Fixed-Bed	0.82(2)
Lignite	HYGAS	Fluidized Bed	0.29(2)
Lignite (Coronach)	This work	Fixed-Bed	0.60 - 1.13
Lignite (Estevan)	This work	Fixed-Bed	0.65 - 1.12

(1) For comparison purposes the phenol/TOC ratio for C_6H_5OH = 1.3

(2) Average reported.

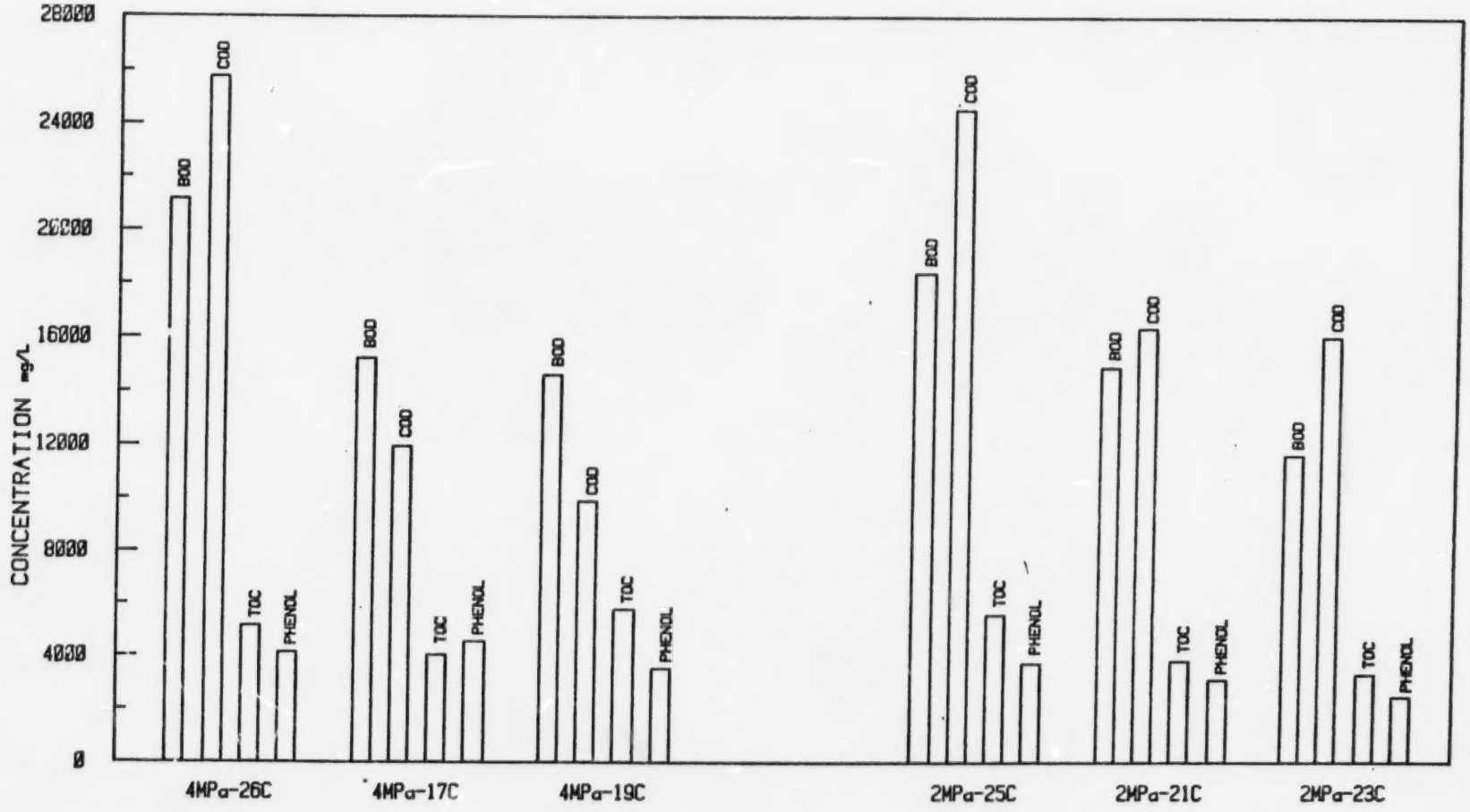


Figure 6.1. COMPARISON OF BOD, COD, TOC AND PHENOL LEVELS IN GASIFICATION CONDENSATES USING CORONACH LIGNITE

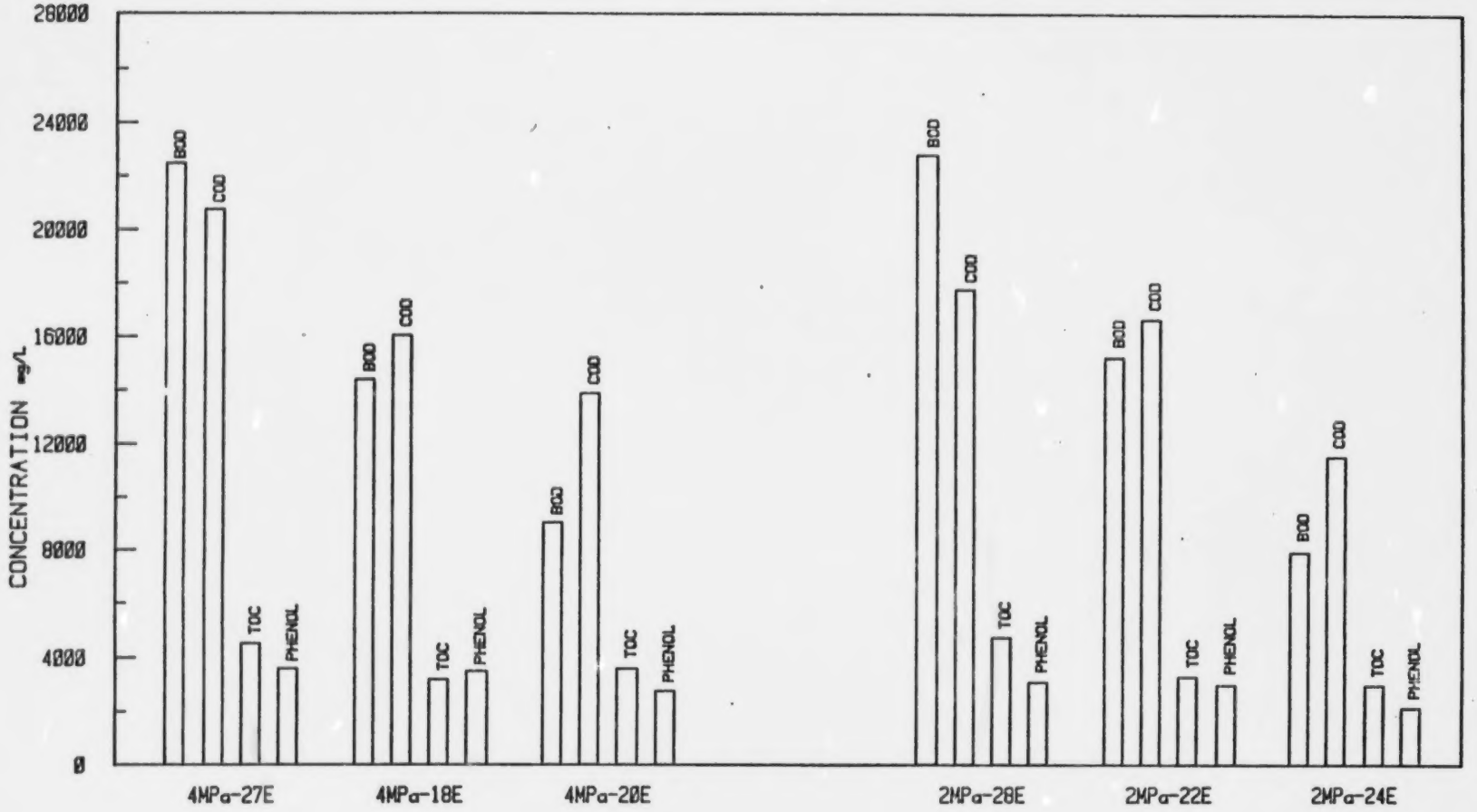


Figure 6.2. COMPARISON OF BOD, COD, TOC AND PHENOL LEVELS IN GASIFICATION CONDENSATES USING ESTEVAN LIGNITE

under proper conditions. Comparison of dissolved oxygen content at the beginning and the end of the incubation period provides a measure of the biochemical oxygen demand. Since COD does not differentiate between stable and unstable forms of organic matter, the COD values will not necessarily correlate with the biochemical oxygen demand. If COD is to include all forms of organic matter, it is fair to expect the COD values to exceed those obtained for BOD. Guidelines for primary and secondary treatment of waste effluents are given in Appendix D.

Studies in assessing the efficiency of activated sludge treatment for the removal of organic constituents from coal gasification process effluents have been conducted by Luthy (1980) and Stamoudis and Luthy (1980). Samples of raw gas quench waters from the HYGAS process at the Chicago Institute of Gas Technology and the slagging fixed-bed gasifier from the Grand Forks Energy Technology Centre were used to evaluate the efficiency of biological oxidation for the removal of organics.

Effluent acid fractions of both HYGAS and SFB condensates showed that nearly 99 percent of extractable and chromatographable organic material comprised phenol and alkylated phenols, and that these compounds were almost completely removed by the activated sludge treatment. Removal efficiency of base-fraction organics was generally good, except for certain alkylated pyridines. They also reported good removal for neutral fraction organics, with the exception for certain alkylated benzenes, and polycyclic aromatic hydrocarbons, especially at low concentrations.

6.2. Solid Waste

At present, there is limited data concerning the nature of solid waste streams at coal gasification plants. Major sources of solid waste at coal gasification plants include:

(a) chars and ashes from the gasification operation and air pollution control;

(b) spent catalysts from shift conversion and methanation;

(c) inorganic solids and sludges from acid gas removal and air and water pollution control;

(d) tar and oil sludges; and

(e) bio-sludges from water pollution control.

The waste stream likely to pose the greatest hazard potential is ash and char from the gasification operation, mainly due to their large volumes. This is followed by inorganic solids and sludges from acid gas removal and air and water pollution control, followed by spent catalyst. The actual quantity and exact chemical composition of each solid waste stream are a function of coal type, specific processes employed and plant design. Due to the wide variations in these parameters, strict comparisons of process effluents between various gasification facilities may not always be appropriate. The solid waste effluents for a typical gasification facility are given in Table 3.2.

In this study the only solid waste produced is the char/ash remaining at the end of each run. The primary objective in this study is to assess the

hazard potential of the solid waste streams generated at coal gasification facilities in comparison with hazardous waste criteria. The U.S. Environmental Protection Agency (EPA) has developed eight categories which are used to determine if a waste is to be deemed hazardous (Hart and Delaney, 1979). These categories are: (a) ignitability; (b) corrosivity; (c) reactivity; (d) toxicity; (e) radioactivity; (f) infectionsness, (g) phytotoxicity and (h) teratogenicity and mutagenicity. In these proposed regulations, EPA relies only on consideration of the first four characteristics because those are the only ones for which established test protocols are available. Hart and Delaney (1979) in their comparison of worst case waste streams from coal gasification facilities with the above hazardous waste criteria found that in the case of gasification ash the leachate may be potentially toxic. Kilpatrick et. al. (1980) studied the impact of trace element content on disposal of two solid waste streams from Wellman-Galusha (Ft. Snelling) gasifier. They used extraction procedures specified by the U.S. Resource Conservation and Recovery Act (RCRA), and compared the leachates produced by extraction with those of general water quality parameters. In all cases, they observed that the elemental concentrations were at least an order of magnitude below the RCRA limits, even though for many elements the lower pH of the RCRA extraction solution (approximately 5 versus approximately 10) resulted in higher concentrations in the leachates than in the corresponding waste water. Table 6.8 gives the percent solubility observed for various elements by Kilpatrick et. al. (1980).

Table 6.8. GASIFIER ASH TRACE ELEMENT CONCENTRATION AND ELEMENT SOLUBILITY FOR THE WELLMAN-GALUSHA (FT. SNELLING) GASIFIER (Kilpatrick, ET. AL. 1980)

Element	Concentration in Ash µg/g	Percent Soluble	Element	Concentration in Ash µg/g	Percent Soluble
Al	38000	0.005	Mg	13000	<0.3
Ag	0.6	0.6	Mn	220	4.5
As	30	0.08	Mo	15	1.8
B	210	1.3	Na	18400	2.6
Ba	5500	0.3	Ni	75	0.9
Be	9	<0.05	P	2000	0.05
Bi	<0.1		Pb	5	0.04
Br	2	3.5	Rb	47	0.8
Ca	48000	<0.5	S	9000	4.1
Cd	0.8	<1.5	Sb	<0.4	<1
Cl	170	12	Se	15	0.6
Co	23	0.5	Si	140000	0.14
Cr	100	0.006	Sn	1.3	60
Cu	81	2.3	Sr	1900	6.3
F	190	31	Th	23	<0.001
Fe	90000	0.04	Ti	4500	0.04
Ga	9	0.07	U	16	<0.002
Ge	1	2.4	V	410	0.03
Hg	1.7	<0.5	W	1	0.9
I	0.2	<2	Zn	20	6.9
K	78600	<2	Zr	180	0.05
Li	48	0.4			

Similar leaching characteristics may be anticipated for the ash residues obtained for the gasification experiments described in this report.

Enrichment factors were calculated for most trace elements from the ratio of the solid waste concentration to the concentration in the coal:

$$\text{Enrichment ratio} = \frac{\text{element concentration } (\mu g/g) \text{ in gasifier residue}}{\text{element concentration } (\mu g/g) \text{ in coal}}$$

Some degree of enrichment (concentration increase) relative to coal would be expected simply due to a loss of carbonaceous matter during gasification. The enrichment due to this source is calculated from the ash content of the gasifier residue. The percentage of ash in the coal (ASTM method) is shown as a horizontal line in Figures E1 through E12 in Appendix E. Individual elements whose enrichment ratios follow the enrichment ratio for ASTM ash from coal may be assumed to be non-volatile. Elements such as Fluorinc (F), Selenium (Se), lead (Pb), Antimony (Sb) and mercury (Hg) are significantly below the ASTM ash enrichment ratio and indicate depletion in the ash, possibly because these metals may form volatile compounds such as metal hydrides or volatile organo-metalics.

7. CONCLUSION

The experimental data show that for almost all of the elements characterised, more than 90 percent of the mass of the elements entering with the coal, will remain in the gasifier residue. During gasification individual elements may:

(a) remain in the solids and be distributed in the ash in the same proportion as in the coal;

(b) be volatilized and exit with the product gas;

(c) be volatilized and recondense as the gas leaves the high temperature zone.

Elements belonging to category (b) and which may be considered to show a volatile behaviour are: mercury (Hg), lead (Pb), selenium (Se), Fluorin (F), and Antimony (Sb).

Increases in concentration for copper (Cu), manganese (Mn) and uranium (U), may be explained from non-uniform physical distribution in the mineral matter in the coal.

Large excesses of chromium, cobalt, nickel and molybdemum were detected in the gasifier residues for all gasification tests. These excesses are undoubtedly due to the erosion of the Hasteloy reactor. Mercury shows complete volatilization during gasification of all coals. The enrichment ratio for mercury was calculated by using the detection limit for mercury in the gasifier residues, thus yielding an upper limit.

Selenium volatility appears to decrease by increase in pressure for both Coronach and Estevan coals. The volatility for selenium in Coronach being slightly larger than for Coronach coal. A major fraction of the selenium is collected in the condensate effluent (Appendix C).

Antimony shows a large volatility in all experiments involving Coronach lignite but not in experiments involving Estevan lignite; this may result from the spread in the antimony content in the lignite samples used for the ratio calculations. However, the volatility for arsenic in all cases is larger than that observed for arsenic contrary to findings elsewhere (Attari, 1973; Kilpatrick, et. al. 1980; Hart and Delaney, 1979).

Trace element concentration in liquid condensate are similar to those observed for other fixed-bed gasification processes. More over the majority of element concentrations are below the allowable concentrations set for water bodies. This will result in less stringent dilution requirements, and the main emphasis will therefore be placed on the removal and destruction of organic contaminants.

8. REFERENCES

Attari, A., "Fate of Trace Constituents of Coal During Gasification", (1973) EPA Report EPA 650/2 78 0 04.

Braunstein, H.M., Copenhaver, E.D., and Prudeur, H.A., "Environmental Health, and Control Aspects of Coal Conversion: An Information Overview", Oak Ridge National Laboratories, Prepared for ERDA, ORNL/EIS-94, (1977).

Cavanaugh, C. D., et. al., "Potentially Hazardous Emissions for the Extraction and Processing of Coal and Oil", EPA report EPA-650/2-75-038.

Cleland, J., Mixon, F., Nichols, D., Sparacino, C., and Wagoner, D., "Pollutants from Synthetic Fuels Production: Facility Construction and Preliminary Tests". EPA Report EPA-600/7-78-171, (1978).

Deutsch, D., "No Health Risks are Seen Yet for Synfuel Workers", Chem. Eng. 88, 51, (1981).

D'Itri, F. M., "The Environmental Mercury Problem", CRC Press, Cleaveland, Ohio, (1972).

Dowdy, R. P., and Matrone, G., J. Nutr (1968) 95, 191.

Ellman, R., Johnson, B., Schohert, H., Paulson, L., and Fegley, M., "Current Status of Studies in Slagging Fixed-Bed Gasification at the Grand Forks Energy Research Centre". Presented at the Lignite Symposium, Grand Forks, North Dakota (1977).

Ellman, R., Paulson, L., and Hajieck, D., "Slagging Fixed-Bed Gasification Project Status at the Grand Forks Energy Technology Centre". Presented at the Lignite Symposium, Grand Forks, North Dakota (1979).

Emmerson, B. T., Ann. Intern. Med. (1968) 68 (2), 488.

Environment Canada (1979), "Analytical Methods Manual", Inland Waters Directorate, Water Quality Branch, Ottawa.

Environment Saskatchewan, "Water Quality Objectives", Water Pollution Control Branch, (1977).

Felder, R., Kelly, R., Ferrell, J., and Rousseau, R., "How Clean Gas is Made from Coal". Environ. Sci. Technol. 14 (6), 658, (1980).

Follinger, H. U. (1953). "Durch Chronische Bleivergiflung Erzeugte Nierenadenome und Carcinone bei Ralten und Ihre Bezughungen Zu den Entsprechenden Neubilkungen des Menschen". Virchaus. Arch. Path. Anat. 323, 694.

Fouts, J. R., and Pohl, R. J., J. Pharmacol. Exp. Ther. (1971) 179, 91.

Friberg, L., Piscator, M., and Nordberg, G., "Symposium on Cadmium in the Environment. A Toxicological and Epidemiological Appraisal". University of Rochester, Rochester, N.Y., June 14-18, 1971.

Friberg, L., and Vostal, J., "Mercury in the Environment - A Toxicological and Epidemiological Appraisal", Karolinska Institute Department of Environmental Hygiene (Stockholm) for the U.S. Environmental Protection Agency, (1971).

Gangwall, S., Groshe, P., Wagoner, D., Minick, D., Sparacino, C., and Zweiainger, R., "Pollutants from Synthetic Fuels Production: Sampling and Analysis Methods for Coal Gasification", EPA Report EPA-600/7-79-201, (1979).

Gilman, J. P. W. and Ruckerbauer, G. M., "Metal Carcinogenesis. I: Observations of the Carcinogenicity of Refinery Dust, Cobalt Oxide and Colloidal Thorium Dioxide", Cancer Research 22 (2), 152-157, (1963).

Hadley, W. M., Miya, T. S., and Bousquet, W., Toxicol. Appl. Pharmacol. (1974) 28, 284.

Hall, H. J., Varga, G. M., and Magee, E. M., "Trace Elements and Potential Pollutant Effects in Fossil Fuels", EPA Contract Report R2-73-249, PB225, 039, 1973.

Hansen, L., Phillips, L., Mangelson, N., and Lee, M., "Analytical Study of the Effluents from a High-Temperature Entrained Flow Gasifier". Fuel 59 (5), 323, (1980).

Hart, F. C. and Delaney, B. T., (1979), "The Impact of RCRA on Coal Gasification Wastes", Fred C. Hart Associates, Inc., DOE/EV/10286-1.

Harvey, S. C., "Heavy Metals" in "The Pharmacological Basis of Therapeutics", (L. S. Goodman and A. Gilman, Eds.), 4th ed., MacMillan, New York, 1970.

Hemphill, D. D., Ann. N.Y. Acad. Sci. (1972) 199, 46.

Hittman Associates, Inc., "Environmental Effects, Impacts and Issues Related to Large Scale Coal Refining Complexes", NTIS FE-1508-T2, (1975).

Holmberg, R.E. and Ferm, V.H., Arch. Environ. Health, 18, 873, (1969).

Hueper, W. D., "Environmental Carcinogenesis and Cancers". Cancer Research 21, 842, (1961).

Intercontinental Engineering, E.P.D. Consultants, Shawinigan Engineering, and Lummus Canada, "Studies of Advanced Electric Power Generation Techniques and Coal Gasification -- Based on the Use of Hat Creek Coal", Prepared for B.C. Hydro and E.M.R. Canada, 2, (1976).

John, M. K., Van Laerhoven, C. J., and Chuah, H. C., Environ. Sci. Technol., (1972) 6 (12), 1005.

Jones, H. C., et. al., "Ecological Effects" in "Trace Contaminants from Coal Combustion", Van Hook, R. I. and Shults, W. D., (Eds.), ERDA 77-64, 1977.

Kilpatrick, M., Magee, R., Emmel, T., and Page, G., "Environmental Assessment. Source Test and Evaluation Report Wellman-Galusha (Ft. Snelling) Low-Btu Gasification". EPA Report EPA-600/7-80-097, (1980).

Kipling, M. D., and Waterhouse, J. A. H., (1967), "Cadmium and Prostatic Carcinoma". Lancet 1, 730.

Lee, A. M., and Fraumeni, "Arsenic and Respiratory Cancer in Man: An Occupational Study". Journal of the National Cancer Institute 43 (b), 1045, (1969).

Lee, Jr., R. E., and Von Lehmden, D. J., J. Air. Poll. Control Ass. (1973) 23 (10), 853.

Louria, D. B., Joselow, M. M., and Browder, A. A., Ann. Intern. Med. (1972) 76 (2), 307.

Luthy, R. G., "Design of Treatability Studies on Hygas Coal Gasification Pilot Plant Waste Waters", Carnegie-Mellon Univ., (1978).

Luthy, R. G., "Design of Treatability Studies on Hygas Coal Gasification Pilot Plant Waste Waters", Carnegie-Mellon University Report to U.S. Department of Energy FE-2496-13, (1980).

Mansour, M. M., Dyer, N. C., Hoffman, L. H., Schulert, A. R., and Brill, A. B., Environ. Res. (1973) 6, 479.

Massey, M. T., Dunlop, R., McMichael, T., and Nakles, D., "Characterization of Effluents from Hygas and CO_2-Acceptor Pilot Plants". DOE Report FE-2496-1, (1976).

Massey, M. J., Dunlop, R., and Luthy, R., "Environmental Assessment in the ERDA Coal Gasification Development Program". DOE Report FE-2496-17, (1978a).

Massey, M. T., Luthy, R., and Pochan, M., "A Synopsis of C-MU Technical Contributions to the DOE Coal Gasification Environmental Assessment Program", DOE Report FE-2496-39, (1978b).

Massey, M. J., Dunlop, R. W., and Luthy, R. G., "Comments Concerning Environmental Assessment Activities at the Bi-Gas Pilot Plant", Carnegie-Mellon Univ., 1978c.

Milham, Jr., S., Strong, T., Environ. Res. (1974) 7 (2), 176.

Mott, W.E., "Processing Needs and Methodology for Waste Waters from the Conversion of Coal", Calif. Univ., Berkeley, (1980).

Nakles, D., "Significance of Process Variables on Liquid Effluent Production in Coal Gasification", DOE Report FE-2496-19, (1978).

Needleman, H. L., Shapiro, I. M., "Dental Lead Levels in Asymptomatic Philadelphia School Children: Subclinical Exposures in High and Low Risk Groups", EPA-NIEMS Conference on Low Level Lead Toxicity, Raleigh, North Carolina, October 1-2, 1973.

Neufeld, R. D., Drummond, C. J., and Johnson, G. E., "Biokinetics of Activated Sludge Treatment of SYNTHANE Fluidized Bed Gasification Waste Waters", Proc. Fuels Division A.C.S. Meeting 1978 Vol. 23, p. 175.

Nishimura, M., "Chemical and Experimental Studies on Acetate Beryllium Disease". Nagoya Journal of Medical Science 28, 17, (1966).

O'Dell, B. L., Amer. J. Clim. Nutr. (1969) 22, 1315.

O'Dell, B. L., Ann. N.Y. Acad. Sci. (1972) 199, 70.

Piperno, E., "Trace Element Emissions: Aspects of Environmental Toxicology", in "Trace Elements in Fuel" (Babu, S. P. ed.), (1975) 194, Advances in Chem. Series, ACS, Washington, D.C.

Potts, C. L., "Cadmium Proteinuria: The Health of Battery Workers Exposed to Cadmium Oxide Dust". Annals of Occupational Hygiene 8, 55, (1965).

Probstein, R., and Gold, H., "Water in Synthetic Fuel Production -- The Technology and Alternatives" MIT Press, Cambridge, 1978.

Reeves, A. L., Deitch, D., and Vorwald, A. J., "Beryllium Carcinogenesis I: Inhalation Exposure of Rats to Beryllium Sulfate Aerosols". Cancer Research 27, 46, (1967).

Rickles, R. N., and Whitenight, D. K., "Environmental Impact Assessment Guidelines for New Source Coal Gasification Facilities", (1980), Wapora Inc., EPA Report EPA-130/6-80-001.

Robertson, D. S. E., Lancet (1970) 1, 518.

Ruch, R. R., Gluskoter, H. J., and Shimp (1974), "Occurrence and Distribution of Potentially Volatile Trace Elements in Coal". EPA Report EPA 650/2-74-054.

Schlinger, W., and Richter, G., "Process Pollutes Very Little", Hydrocarbon Process. 59 (10), 66, (1980).

Schroeder, H. A., Environment (1971) 13 (8), 18.

Schroeder, H., "Trace Elements and Man", (1973) Devin-Adair, Old Greenwich, Connecticut.

Schroeder, H., "The Poisons Around Us -- Toxic Metals in Food, Air, and Water", Indiana Univ. Press., Bloomington, (1974).

Shacklette, H. T., Sauer, H. I., and Miesch, A. J., Geol. Soc. Amer. Bull (1972) 83 (4), 1077.

Smith, S., and Larson, E., J. Biol. Chem. (1946) 163, 29.

Stamoudis, V. C., and Luthy, R. G., "Biological Removal of Organic Constituents in Quench Waters from High-Btu Coal Gasification Pilot Plants", Argonne National Laboratory Report ANL/PAG-2 (1980).

Stern, A. C., Environ. Sci. Technol. (1974) 8 (1), 16.

Stobinger, H.E., "Industrial Hygiene and Toxicology", Patty, F.A., (ed.), Interscience Publishers, New York, (1963).

Sunderman, F. W., and Donnelly, A. J., "Studies of Nickel Carcinogenesis in Metastasizing Pulmonary Tumors in Rats Induced by the Inhalation of Nickel Carbonyl". Amer. J. Clin. Pathology 46, 1027, (1965).

Tarr, J., and Damme, C., "The Special Relevance of Cancer", Chem. Eng. 85 (10), 86, (1978).

Torrey, S., ed. "Trace Contaminants from Coal", Noyes Data, Park Ridge, New Jersey, 1978.

Vallee, B. L. and Ulmer, D. D., Annu. Rev. Biochem. (1972) 41, 91.

Wager, W. D., et. al. (1969), "Comparative Chronic Inhalation Toxicity of Beryllium Ores, Bertrandite, and Beryl, with Production of Pulmonary Tumors by Beryllium", Toxicology and Applied Pharmacology, 15, 10.

Waldbott, G., "Health Effects of Environmental Pollutants", (1973) C. V. Mosby Company, Saint Louis.

Welt, L. G., and Blythe, W. B., "Anions: Phosphate, Iodide, Fluoride, and Other Anions", in "The Pharmacological Basis of Therapeutics" (L. S. Goodman and A. Gilman, Eds.), (1970) 4th ed., Macmillan, New York.

Wickstrom, G. (1972), "Arsenic in the Ecosystem of Man", Work Environment Health, 9 (1), 2.

Wood, J. M., Kennedy, F. C., and Rosen, C. G., Nature (1968) 220, 173.

Woolrich, P. F., Amer. Ind. Hyg. Ass. J. (1973) 34 (5), 217.

Zawirsica, B., and Medras, K., "Tumors and Disorders in the Porphyrin Metabolism in Rats with Chronic Experimental Lead Poisoning I: Morphological Studies", ZBL Ablg. Path. Anat., (1968), 3, 1.

Appendix A

UNITED STATES AND CANADIAN AIR QUALITY STANDARDS

APPENDIX A

Table A.1. E.P.A. AIR QUALITY EMISSION STANDARDS

a) New Source Performance Standards for Waste Water from Petroleum Refinery and By-Product Coking Facilities (40CFR 419 and 420)

Industry (kg pollutant per MJ, 30 day feedstock)(1)

Pollutant	Petroleum Refinery	By-Product Coke
BOD	99 - 436	205
TSS	62 - 278	104
Ammonia (as N)	20 - 172	104
Oil and Grease	30 - 107	104
Phenols	0.66 - 3.0	5.12
Sulfides	0.51 - 2.5	2.5

b) Summary of Standards of Performance for Fossil Fuel-Fired Steam Elective Generating Units for which Construction Commenced after September 18, 1978 (40CFR60)

Pollutant	Emission Limit
Sulfur Dioxide	520 ng/J(2)
Nitrogen Oxides	260 ng/J(3,4)
Particulate Matter	13 ng/J(5)
Opacity	20 percent(6)

(1) Assumes heating values of 43.13 MJ/L for crude oil and 27.91 MJ/kg for coal, with coke yield of 0.69 kg coke/kg coal.

(2) For coal a 90 percent reduction in pote tial SO_2 emissions is

Table A.1. (Continued)

required at all times except when emissions to the atmosphere are less than 260 ng/J. When SO_2 emissions are less than 260 ng/J, a 70 percent reduction limit is required. (1 ng = 10^{-9} g)

(3) Except: (a) the limits for coal desolved gaseous, liquid and solid fuels, and for subbituminous coal, are 210 ng/J; (b) the limit of any fuel containing more than 25 percent (by weight) lignite mined in North Dakota, South Dakota or Montana and combusted in a slag tap furnace is 340 ng/J; (c) any fuel containing more than 25 percent (by weight coal) refuse is exempt from NO_x. Other deviations from the 260 ng/J limit for liquid and gaseous fuel are in 40CFR 60.44a.

(4) For coal, a 65 percent reduction in potential nitrogen oxide emissions is required.

(5) For coal, a 99 percent reduction in potential particular emissions is required.

(6) Except for one 6 minute period per hour of not more than 27 percent opacity.

Table A.2. SUMMARY OF U.S.A. AMBIENT AIR QUALITY STANDARDS (40CFR 50)

Emission	Standard	
	Primary	Secondary
Sulfur Dioxide	80 $\mu g/m^3$ annual arithmetic mean	1300 $\mu g/m^3$ maximum 3-hour concentration*
	365 $\mu g/m^3$ maximum 24-hour concentration*	
Particulate Matter	75 $\mu g/m^3$ annual geometric mean	150 $\mu g/m^3$ maximum 24-hour concentration*
	260 $\mu g/m^3$ maximum 24-hour concentration*	60 $\mu g/m^3$ annual geometric mean (as a guideline in assessing implementation plants)
Hydrocarbons	160 $\mu g/m^3$ maximum 3-hour concentration	160 $\mu g/m^3$ maximum 3-hour concentration*
Nitrogen Dioxide	100 $\mu g/m^3$ annual arithmetic mean	100 $\mu g/m^3$ annual arithmetic mean
Ozone	235 $\mu g/m^3$ maximum 1-hour concentration	235 $\mu g/m^3$ maximum 1-hour concentration*
Carbon Monoxide	10 mg/m^3 maximum 8-hour concentration*	10 mg/m^3 maximum 8-hour concentration*
	40 mg/m^3 maximum 1-hour concentration*	40 mg/m^3 maximum 1-hour concentration
Lead	1.5 $\mu g/m^3$ maximum calendar quarterly average	1.5 $\mu g/m^3$ maximum calendar quarterly average

* The maximum allowable concentration may be exceeded for the prescribed period once each year without violating the standard.

Table A.3. SASKATCHEAN AMBIENT AIR QUALITY STANDARDS(1)

Pollutant	Average Concentration for Applicable Time Period				
	1 Hour	8 Hours	24 Hours	30 Days	Annual
Suspended Particles			120 $\mu g/m^3$		*70 $\mu g/m^3$
Setteable Particles				2.0 mg/cm^2	
Soil Index			1.5 COH units		
Potash				0.15 mg of K per cm^2 or 0.15 mg of Cl per cm^2	
Sulfur Dioxide	450 $\mu g/m^3$		150 $\mu g/m^3$		**30 $\mu g/m^3$
Sulfation				30 mg/100 cm^2	
Carbon Monoxide	15 mg/m^3	6 mg/m^3			
Oxidants (ozone)	100 $\mu g/m^3$		30 $\mu g/m^3$		
Nitrogen Dioxide	400 $\mu g/m^3$		200 $\mu g/m^3$		**10 $\mu g/m^3$

(1) Environment Saskatchewan, Regulations under the Air Pollution Control Act. Saskatchewan Regulation 21/75, Order in Council 1219/75.

* Geometric mean.
** Arithmetic mean.

Appendix B

METHOD OF ANALYSIS USED FOR CONDENSATE COLLECTED DURING GASIFICATION OF LIGNITE COALS

Appendix B. METHOD OF ANALYSIS USED FOR CONDENSATE COLLECTED DURING GASIFICATION OF LIGNITE COALS

B.1. Trace Elements

The methods used for the condensate analysis are those used by the Water Ouality Branch Laboratories for conducting environmental analyses on surface waters, waste waters, sediments and other aquatic media (Environment Canada, 1979). The procedures are periodically modified as a result of improvements brought about by steady advances in technology. The accuracy and precision data that have been established for procedures using these methods are generally the result of single laboratory testing. Interlaboratory studies are currently being conducted to generate specifications for precision, accuracy and detection limit. The methods used are given in Table C.1 and refer to the code specified in the methods handbook.

The high organic content of the samples posed some problems during the sample preparation stage. It was found that for all analysis excluding boron and fluoride, the addition of perchloric acid was required along with the nitric acid specified in the NAOUADAT procedure to break down the organics. The samples were evaporated to 1/10 volume in nitric acid, then 1 mL perchloric acid was added for each 10 mL of sample and the sample was reheated. This procedure produced clear bright yellow solutions. The samples were then diluted back to original volume with distilled deionized water.

This solution was then used for the analysis of all metals other than B, F, Sb, As, Se, and Hg. The nitric-sulfuric acid digestion for As, Se, and Sb was adequate to break down organics and was used as outlined in the NAQUADAT procedures for these three parameters.

Mercury was attempted by NAQUADAT procedure 80011 but the organic content of the samples used all the available $KMnO_4$ in the automated method and produced "gasing" problems. The analysis was finally peformed via NAQUADAT procedure 80013 with excess $KMnO_4$.

At present there does not exist a NAQUADAT procedure for Tellurium. This element was therefore analysed by direct atomic absorption after digestion with perchloric and nitric acid as indicated above.

B.2. Physical Parameters

The samples for BOD_5, COD, TOC and phenol determinations were split into two parts. Part A for phenol, COD and TOC analysis was preserved by addition of 5 mL 12.5 percent H_2SO_4 per 250 mL of sample.

The above preservation methods were adapted from Luthy (1978), who has prepared a manual of methods for the preservation of coal gasification waste waters. He has identified some special characteristics of coal gasification waste waters and proposed a set of preservation and analytical procedures. The areas of concern involve:

(a) The representativeness of waste water solids sampling and solids intereference.

(b) Digestion of solids in preserved samples during storage.

(c) Influence of NH_3 and CO_2 on total dissolved solids.

(d) High buffering capacity of the waste water.

(e) High concentrations of effluent constituents.

(f) Complex interaction of CN^-, SCN^- and S^{2-}.

Table B.1. PROCEDURES FOLLOWED IN THE ANALYSIS OF GASIFICATION CONDENSATES

Element	NAQUADAT(1) Procedure No.		Detection Limit(2) µg/mL
As	33004L	(A.A. flameless)	0.0002
B	05106L	(auto analyser)	0.01
Ba	56001L	(A.A.)	0.1
Be	04002L	(A.A.)	0.001
Cd	48002L	(A.A.)	0.001
Co	27002L	(A.A.)	0.001
Cr	24002L	(A.A.)	0.01
Cu	29005L	(A.A.)	0.001
F	09105L	(specific ion electrode)	0.05
Hg	80013L	(A.A. flameless)	0.0005
Mn	25004L	(A.A.)	0.001
Mo	42001L	(A.A.)	0.05
Ni	28002L	(A.A.)	0.001
Pb	82002L	(A.A.)	0.004
Sb	51003L	(A.A.)	0.0005
Se	34005L	(A.A.)	0.0002
Tl	81003l	(A.A.)	0.1
U	92111L	(Fluorometry)	0.0001
V	23002L	(A.A.)	0.001
Zn	30005L	(A.A.)	0.001
Parameter			
BOD_5	08202L		0.1
COD	08304L		5.0
TOC	06001L		0.2
Phenol	--		0.002

(1) Methods used by the Canadian Water Quality Branch Laboratories (Environment Canada, 1979).

(2) The detection limits are based on single laboratory testing.

Table B.2. ANALYSIS OF LIQUID CONDENSATE OBTAINED FROM GASIFICATION OF CORONACH LIGNITE

Run #	25C-2MPa	21C-2MPa	23C-2MPa	26C-4MPa	17C-4MPa	19C-4MPa
Trace Elements	µg/mL					
As	0.038	0.036	0.052	0.039	0.036	0.28
B	11	8	9	6	9	9
Ba	0.2	0.2	0.3	0.2	0.1	0.3
Be	<0.001	<0.001	0.001	<0.001	0.002	0.003
Cd	<0.001	<0.001	<0.001	0.001	<0.001	<0.001
Co	0.003	0.003	0.006	0.003	0.002	0.11
Cr	<0.01	<0.01	<0.01	<0.01	0.10	<0.01
Cu	0.054	0.009	0.025	0.033	0.041	0.015
F	0.32	0.49	0.36	0.16	0.58	0.36
Hg	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Mn	0.04	0.012	0.02	0.03	0.01	0.017
Mo	0.24	0.31	0.31	0.26	0.46	0.66
Ni	0.057	0.004	0.042	0.083	0.039	0.009
Pb	0.004	<0.004	0.006	0.011	0.013	0.010
Sb	0.005	0.006	0.010	0.005	0.005	0.003
Se	0.094	0.049	0.006	0.102	0.064	0.024
Te	<0.1	<0.1	<0.1	0.1	<0.1	0.3
Tl	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
U	0.0017	0.0065	0.0008	0.0010	0.0009	0.0010
V	<0.001	0.001	<0.001	<0.001	0.004	0.001
Zn	0.008	0.003	<0.001	0.013	0.008	0.074
Dilution Factor	2.0	2.0	2.0	3.33	2.5	2.0

Table B.3. ANALYSIS OF LIQUID CONDENSATE OBTAINED FROM GASIFICATION OF ESTEVAN LIGNITE

Run #	28E-2MPa	22E-2MPa	24E-2MPa	27E-4MPa	18E-4MPa	20E-4MPa
Trace Elements	µg/mL					
As	0.029	0.052	0.042	0.052	0.036	0.045
B	10	6	6	7	5	5
Ba	<0.1	0.2	0.2	0.2	0.1	0.1
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cd	<0.001	0.001	<0.001	<0.001	<0.001	<0.001
Co	<0.001	<0.001	0.003	<0.001	0.46	0.022
Cr	0.07	<0.01	<0.01	0.03	<0.01	<0.01
Cu	0.11	0.057	0.023	0.24	0.024	0.024
F	0.4	0.52	0.49	0.54	0.49	0.36
Hg	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Mn	0.03	0.04	0.02	0.01	0.022	<0.01
Mo	0.20	0.68	0.17	0.35	0.35	0.72
Ni	0.23	0.090	0.056	0.005	0.005	0.003
Pb	<0.004	<0.004	0.005	<0.004	0.014	0.004
Sb	0.007	0.008	0.010	0.008	0.008	0.0380
Se	0.030	0.003	0.007	0.005	0.019	0.002
Te	<0.1	<0.1	<0.1	<0.1	0.2	<0.1
Tl	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
U	0.0012	0.0008	0.0010	0.0012	0.0007	0.0008
V	<0.001	0.001	<0.001	<0.001	0.001	<0.001
Zn	<0.001	0.015	0.016	<0.001	0.077	0.006
Dilution Factor	2.0	2.0	2.0	2.0	2.5	2.0

Table B.4. PHYSICAL PARAMETERS OBTAINED FOR CONDENSATES COLLECTED DURING THE GASIFICATION FROM CORONACH AND ESTEVAN LIGNITES

Run #	BOD mg/L	COD mg/L	TOC mg/L	Phenol mg/L	Phenol/TOC Ratio	pH	Conductivity mS
Coronach							
25C-2MPa	18 400	24 500	5 550	3 700	0.97	8.7	36.4
21C-2MPa	14 900	16 350	3 800	3 100	0.82	8.7	27.7
23C-2MPa	11 600	16 000	3 300	2 450	0.74	8.5	23.6
26C-4MPa	21 100	25 800	5 150	4 100	0.80	8.8	30.1
17C-4MPa	15 200	11 900	4 000	4 500	1.13	8.8	30.5
19C-4MPa	14 550	9 900	5 800	3 500	0.60	8.6	25.6
Estevan							
28E-2MPa	22 800	17 800	4 700	3 050	0.65	8.8	45.7
22E-2MPa	15 200	16 600	3 300	2 950	0.89	8.8	47.2
24E-2MPa	7 950	11 500	3 000	2 150	0.72	8.8	34.9
27E-4MPa	22 500	20 750	4 550	3 650	0.80	8.8	42.0
18E-4MPa	14 400	16 000	3 175	3 550	1.12	8.9	43.0
20E-4MPa	9 040	13 900	3 650	2 800	0.77	8.5	30.5

BOD = Biological Oxygen Demand
COD = Chemical Oxygen Demand
TOC = Total Organic Carbon

Appendix C

METHOD OF ANALYSIS USED FOR COAL ASH AND GASIFICATION RESIDUE SAMPLES

Appendix C. METHOD OF ANALYSIS USED FOR COAL ASH AND GASIFICATION RESIDUE SAMPLES

C.1. Coal Samples

The coal samples were analysed on an as received basis using the following techniques:

C.1.1. Volatile Elements (As, Se, Hg and Sb)

The coal was digested in a Parr Oxygen Bomb to destroy the combustibles and retain the volatile components. Analysis for the individual elements was performed on the bomb washings. The elements As, Se and Sb were determined by atomic absorption using hydride generation. Mercury was determined by cold vapour atomic absorption.

C.1.2. Fluoride

For fluoride determinations, the samples were mixed with a standard flux and fused for one hour. The solidified fusions were then dissolved in deionized water and neutralized before analysis. The fluoride ion activity was then measured by specific ion electrode detection.

C.1.3. Uranium

For uranium determinations, the samples were digested using a combination of nitric and perchloric acids. An alignot of the digested

solution was used to extract the uranium into an organic solvent. This solution is then fused with a standard flux and analysed for uranium by Atomic fluorescence.

C.1.4. Tellurium

The samples were digested using a combination of nitric and hydrochloric acids. An aliquot of the digested sclution was used to extract the tellurium into an organic solvent. The extract was then analysed for tellurium by direct flame atomic absorption.

C.1.5. Trace Elements

The remaining trace analysis were performed on the ash obtained from ashing overnight at 700°C. The analysis methods used are those described under gasification residue samples.

C.2. Gasification Residue Samples

The determination of fluoride, tellurium and uranium in the char/ash samples was done as described in the analysis of the coal samples. All remaining analyses were performed on the gasification residue samples on an as received basis.

C.2.1. Trace Elements

The char/ash and ashed coal samples were digested using a combination of acids ($HF/HNO_3/HCl/HClO_4$) so as to decompose any silicate

matrices present. Samples were analysed for metals by inductive coupled argon plasma spectrograph. Cadmium, cobalt, chromium, copper, molybdenum, nickel, lead, vanadium and zinc were cross checked by direct flame atomic absorption.

C.2.2. Volatile Elements (As, Hg, Sb and Se)

The gasification residue samples were digested using a mixture of nitric and perchloric acids, and analysed by hydride generation atomic absorption for As, Sb and Se. Cold vapour atomic absorption was used for the mercury determination.

C.2.3. Boron

The gasification residue and ash samples were prepared using a controlled low temperature nitric acid digestion. The resulting solutions were analysed for Boron by inductively coupled argon plasma spectrograph.

Note: All analyses were conducted using a 50 percent duplication rate. Blanks and certified reference standards were analysed concurrently with each separate digestion technique so as to compensate for any contamination that could have occurred during digestion.

Table C.1. ANALYSIS OF GASIFICATION RESIDUES FROM ESTEVAN LIGNITE(1)

Run #	28E-2MPa	22E-2MPa	24E-2MPa	27E-4MPa	18E-4MPa	20E-4MPa	Detection Limit
			Major Elements %				
Al_2O_3	8.75	8.26	8.41	6.86	9.13	5.92	0.01
Fe_2O_3	10.2	8.55	10.5	7.51	11.9	6.71	0.01
CaO	28.5	24.9	25.5	21.1	26.3	17.3	0.01
MgO	10.9	9.37	9.58	8.06	10.5	6.81	0.01
Na_2O	4.48	4.26	4.07	3.22	3.83	2.80	0.01
K_2O	0.40	0.40	0.40	0.28	0.33	0.25	0.01
			Trace Elements µg/g				
As	87.0	66.0	88.0	68.5	80.0	48.0	0.10
B	2210	2650	2780	1910	2450	1860	1.0
Ba	1650	2670	3440	545	1700	1980	0.1
Be	27.1	23.8	23.8	20.3	25.8	17.4	0.3
Cd	1.6	1.1	8.7	20.0	4.9	13.0	0.5
Co	65.0	125	63.0	46.0	175	138	3.0
Cr	786	694	1260	530	1290	894	1.0
Cu	105	96.0	103	81.0	116	103	1.0
F	290	400	255	435	160	350	1.5
Hg	<	<	<	<	<	<	0.10
Mn	740	595	74.0	563	870	581	0.3
Mo	830	2780	970	640	2530	1770	5.0
Ni	3350	8220	2980	1640	8830	6830	1.0
Pb	15.0	26.0	<	20.0	20.0	62.0	10
Sb	3.40	3.10	2.80	3.15	2.90	2.20	0.10
Se	1.10	0.58	0.65	0.97	3.00	2.10	0.10
Sn	<	21.1	6.2	<	8.5	4.5	3.0
Sr	4300	3890	4030	3120	3820	2700	0.1
Ti	1390	1240	1290	1050	1380	887	1.0
U	20.0	17.0	13.5	14.0	17.6	11.5	0.1
V	78.0	64.9	70.5	58.4	56.7	45.2	1.0
Zn	117	115	114	98.0	128	83.0	1.0
PO_4	1980	1780	1790	1470	2050	1310	40

(1) The values are on an as received basis. No correction has been made for carbon contents.

< below detection limit.

Table C.2. ANALYSIS OF GASIFICATION RESIDUES FROM CORONACH LIGNITE(1)

Run #	25C-2MPa	21C-2MPa	23C-2MPa	26C-4MPa	17C-4MPa	19C-4MPa	Detection Limit
			Major Elements %				
Al_2O_3	12.7	16.1	14.5	17.0	17.6	17.4	0.01
Fe_2O_3	10.2	11.7	11.9	12.3	12.2	12.2	0.01
CaO	14.6	18.5	16.6	19.2	19.7	19.7	0.01
MgO	3.76	4.75	4.27	4.84	5.18	5.23	0.01
Na_2O	2.73	3.56	3.57	3.41	4.00	3.71	0.01
K_2O	0.33	0.43	0.41	0.45	0.44	0.43	0.01
			Trace Elements µg/g				
As	28.0	56.5	61.0	56.0	67.5	59.5	0.10
B	1730	2030	2000	1640	2280	1780	1.0
Ba	1730	925	3640	2220	1260	5140	0.1
Be	5.0	6.4	5.8	5.8	7.3	6.7	0.3
Cd	1.1	12.5	4.8	1.3	18.0	12.5	0.5
Co	364	159	115	215	154	138	3.0
Cr	3020	923	499	1590	1180	914	1.0
Cu	140	151	120	151	151	146	1.0
F	200	140	210	215	180	290	1.5
Hg	<	<	<	<	<	<	0.10
Mn	1190	907	96.3	1050	1180	1020	0.3
Mo	5200	2720	2940	2970	1930	1050	5.0
Ni	13800	8080	7610	8100	7170	7570	1.0
Pb	30.5	44.0	46.0	130	30.0	33.0	10.0
Sb	0.32	0.33	0.48	0.21	<	0.29	0.10
Se	0.46	0.87	0.96	1.50	2.25	2.10	0.10
Sn	<	6.8	5.7	3.7	<	6.3	3.0
Sr	1940	2460	2240	2490	2620	2660	0.1
Ti	2140	2720	2460	2880	3040	3000	1.0
U	4.0	11.0	5.0	6.5	11.5	6.5	0.1
V	53.5	69.5	71.4	70.1	85.1	78.6	1.0
Zn	66.0	100	85.0	93.0	127	83.5	1.0
PO_4	3310	3950	3650	4150	4500	4110	40

(1) The values are on an as received basis. No correction has been made for carbon content of the ash.

< below detection limit.

Table C.3. ANALYSIS OF LIGNITE COALS USED IN GASIFICATION EXPERIMENTS

Coal Type	Coronach		Estevan	
Run #	25C-2MPa	21C-2MPa	28E-2MPa	22E-2MPa
	Major Elements(1) %			
Al_2O_3	15.0	15.6	8.05	7.98
Fe_2O_3	10.4	10.3	8.11	8.15
CaO	16.9	17.3	25.2	25.2
MgO	4.40	4.56	9.75	9.82
Na_2O	3.41	3.30	4.76	4.75
K_2O	0.40	0.40	0.46	0.41
	Trace Elements(1) µg/g			
As(3)	0.23	0.14	0.30	0.31
B	2130	2140	2770	2870
Ba	574	430	334	390
Be	5.0	4.1	26.8	23.1
Cd	<0.5	<0.5	<0.5	<0.5
Co	18.0	14.0	18.0	21.0
Cr	80.6	67.5	46.0	44.0
Cu	111	120	81	83
F (3)	68	120	76	60.0
Hg(3)	0.12	<0.10	0.20	0.15
Mn	645	641	417	409
Mo	27.0	26.5	99.0	110
Ni	52.0	45.0	76.0	94.0
Pb	64.5	41.5	67.0	138
Sb(3)	7.08	6.98	5.90	6.26
Se(3)	0.59	0.53	0.21	0.21
Sn	<3.0	<3.0	<3.0	<3.0
Sr	2150	2230	3770	3840
Ti	2540	2650	1220	1160
U	3.8	3.9	6.5	6.3
V	72.8	73.4	77.2	70.8
Zn	92.5	92.5	125	170
PO_4	3860	3940	1660	1690
Ash(2)	13.0	12.9	7.72	7.92

(1) concentration in ash.
(2) moisture free basis.
(3) concentration in coal, dry basis.

Table C.4. PROXIMATE ANALYSIS FOR ESTEVAN(1) AND CORONACH LIGNITE USED IN TESTS

Run #	Moisture % as received	Ash(2) %	Volatile Matter(2) %	Fixed Carbon(3) %
Coronach				
25C-2MPa	21.53	9.72	42.28	48.00
21C-2MPa	25.33	11.23	42.38	46.40
23C-2MPa	23.29	13.63	41.71	44.67
17C-4MPa	21.91	12.44	42.07	46.70
19C-4MPa	23.11	11.24	41.90	46.10
26C-4MPa	24.69	12.01	42.03	45.54
Estevan				
28E-2MPa	26.88	7.95	41.78	50.28
22E-2MPa	24.90	8.00	41.22	50.79
24E-2MPa	27.43	7.04	41.39	51.58
27E-4MPa	27.43	7.08	41.68	51.24
18E-4MPa	27.17	7.00	41.39	51.61
20E-4MPa	27.39	7.56	40.66	51.79

(1) Souris Valley Mine, Estevan

(2) Moisture free basis.

(3) % Fixed Carbon = 100 - (% moisture + % ash + % volatile matter)

Table C.5. ULTIMATE ANALYSIS FOR ESTEVAN AND CORONACH LIGNITE SAMPLES(1)

Run #	Carbon %	Nitrogen %	Hydrogen %	Oxygen(2) %
Coronach				
25C-2MPa	61.40	1.04	4.20	23.64
21C-2MPa	61.14	1.03	4.17	22.43
23C-2MPa	60.28	1.07	4.13	20.89
17C-4MPa	59.52	1.07	3.97	22.84
19C-4MPa	60.51	1.06	4.06	23.13
26C-4MPa	60.68	1.03	3.98	22.30
Estevan				
28E-2MPa	64.78	1.46	4.24	21.57
22E-2MPa	65.40	1.72	4.26	20.62
24E-2MPa	64.60	1.60	4.27	22.49
27E-4MPa	67.49	1.56	4.33	19.54
18E-4MPa	65.76	1.51	4.19	21.54
20E-4MPa	65.85	1.60	4.19	20.80

(1) Dry basis.

(2) By difference (includes sulfur).

Table C.6. ANALYSIS OF GASIFICATION RESIDUES

Run #	% Ash	% C	% H
Coronach			
25C-2MPa	76.80	18.89	1.02
21C-2MPa	90.14	9.01	0.33
23C-2MPa	83.58	13.51	0.10
17C-4MPa	97.17	2.81	0.13
19C-4MPa	91.94	7.61	0.16
26C-4MPa	97.03	3.87	0.18
Estevan			
28E-2MPa	87.65	9.05	0.11
22E-2MPa	77.95	17.74	0.25
24E-2MPa	79.15	13.46	0.34
27E-4MPa	69.47	24.83	1.58
18E-4MPa	85.05	11.10	0.38
20E-4MPa	55.44	38.18	0.56

Appendix D

SURFACE WATER QUALITY OBJECTIVES
(Environment Saskatchewan, 1977)

Appendix D. SURFACE WATER QUALITY OBJECTIVES (Environment Saskatchewan, 1977)

The objectives have been prepared in cooperation with the Provinces of Saskatchewan, Alberta and Manitoba and represent water quality suitable for most uses either through direct use or prepared for use by an economically practical degree of treatment.

Table D.1. SURFACE WATER QUALITY OBJECTIVES

Parameter	Objectives
1. Bacteriology (Coliform Group)	(a) In waters to be withdrawn for treatment and distribution as a potable supply or used for outdoor recreation other than direct contact, at least 90 percent of the samples (not less than five samples in any consecutive 30-day period) should have a total coliform density of less than 5000 per 100 mL and a fecal coliform density of less than 1000 per 100 mL. The maximum permissible limit of total coliform organisms in a single sample shall be determined by the Department, based on the type and degree of polution and other local conditions (existing within the water shed). (b) In waters used for direct contact recreation or vegetable crop irrigation, the geometric mean of not less than five samples taken over not more than a 30-day period should not exceed 1000 per 100 mL total coliforms, nor 200 per 100 mL fecal coliforms, nor exceed these numbers in more than 20 percent of the samples examined during any month, nor exceed 2400 per 100 mL total coliforms on any day.
2. Dissolved Oxygen	A minimum of 5 mg/L at any time.
3. Biochemical Oxygen Demand	Dependent on the assimilative capacity of the receiving water. The BOD must not exceed a limit which would create a dissolved oxygen content of less than 5 mg/L.

Table D.1 (Continued)

Parameter	Objectives
4. Suspended Solids	Not to be increased by more than 10 mg/L over background value.
5. pH	To be in the range of 6.5 to 8.5 pH units but not altered by more than 0.5 pH units from background value.
6. Temperature	Not to be increased by more than 3°C above ambient water temperature.
7. Odour	The cold (20°C) threshold odour number not to exceed eight.
8. Color (apparent)	Not to be increased more than 30 colour units above natural value.
9. Turbidity	Not to exceed more than 25 turbidity units over natural turbidity.
10. Organic Chemicals	

Constituent	Maximum Concentration (mg/L)
Carbon Chloroform Extract (CCE) (includes Carbon Alcohol Extract)	0.2
Methyl Mercaptan	0.05
Methylene Blue Active Substances	0.5
Oil and Grease	- substantially absent no irridescent sheen
Phenolics	0.005
Resin Acids	0.1
Pesticides	To provide reasonably safe concentrations of these materials in receiving waters an application shall not exceed 1/100 of the 48 hour Tl_m. Consideration must also be given to sublethal effects such as taste and odour generation.

Table D.1 (Continued)

Parameter Objectives

11. Inorganic Chemicals

Constituent	Maximum Concentration (mg/L)
Boron (B)	0.5
Copper (Cu)	0.02
Fluoride (F^-)	1.5
Iron (Fe)	0.3
Manganese (Mn)	0.05
*Nitrogen (Total Inorganic and Organic)	1.0
*Phosphorus as PO_4 (Total Inorganic and Organic)	0.15 (0.05 as P)
Sodium (Na) (as percent of cations)	between 30 and 75
Sulfide (S^{2-})	0.05
Zinc (Zn)	0.05

* These objectives are presently under study and may require adjusting according to naturally occurring concentrations or conditions.

Note: The predominant cations of sodium (Na^+), calcium Ca^{2+}) and magnesium (Mg^{2+}) and anions of sulfate (SO_4^{2+}), chloride (Cl^-) and bicarbonate (HCO_3^{2-}) are too variable in the natural water quality state to attempt to define limits. Nevertheless, in order to prevent impairment of water quality, where effluents containing these ions are discharged to a water body, the permissible concentration will be determined by the Department in accordance with existing quality and use.

12. Toxic Chemicals

Constituent	Maximum Concentration (mg/L)
Arsenic (As)	0.01
Barium (Ba)	1.0
Cadmium (Cd)	0.01
Chromium (Cr)	0.05
Cyanide (CN^-)	0.01
Lead (Pb)	0.05
Mercury (Hg)	0.0001
Selenium (Se)	0.01
Silver (Ag)	0.05

Table D.1 (Continued)

Parameter	Objectives
13. Radioactivity	Gross Beta not to exceed 37 Bq/L(1) Radium 226 not to exceed 0.1 Bq/L Strontium 90 not to exceed 0.4 Bq/L
14. Unspecified Substances	Substances not specified herein should not exceed values which are considered to be deleterious for the most critical use as established by the Department.

Note: Unless specified, parameter concentrations refer to "total" measurements.

(1) One Becquerel (Bq)/L corresponds to approximately 27 Picocuries $(pCi)\cdot L^{-1}$.

Table D.2. GUIDELINES FOR PRIMARY TREATMENT OF SEWAGE (INCLUDING ANAEROBIC LAGOONS)

	Parameter	% Removal	Effluent Value
1.	BOD (5-day at 20°C)	25 - 45	100 - 150 mg/L
2.	Coliform Bacteria	40 - 60	25 x 10^6/100 mL
3.	MBAS	Nil	--
4.	Settleable Solids	70 - 90	0.5 - 1.0 mg/L
5.	Suspended Solids	35 - 65	100 - 150 mg/L

Table D.3. GUIDELINES FOR SECONDARY TREATMENT OF SEWAGE (INCLUDING AREATED LAGOONS)

	Parameter	% Removal	Effluent Value
1.	Ammonia N	--	10 - 20 mg/L
2.	BOD (5-day at 20°C)	85 - 95	15 - 30 mg/L
3.	Coliform Bacteria	99.5-99.9	20000 - 200000 per 100 mL
4.	MBAS	80 - 95	0.2 - 0.8 mg/L
5.	Dissolved Oxygen	--	3 - 5 mg/L
6.	Oil and Grease (Esther Solubles)*	--	15 - 25 mg/L
7.	pH	--	5.5 - 10.5
8.	Phenolics*	--	20 - 40 mg/L
9.	Suspended Solids	85 - 95	15 - 30 mg/L
10.	Phosphorous as PO_4	--	15 - 30 mg/L

* Applied to any effluent regardless of treatment.

Table D.4. GUIDELINES FOR CONVENTIONAL AEROBIC LAGOONS

	Parameter	% Removal Winter	% Removal Summer	Effluent Value (Summer)
1.	BOD (5-day at 20°C)	25 - 65	85 - 95	15 - 30 mg/L
2.	Coliform Bacteria	>90	>99.5	20000 - 200000 per 100 mL
3.	MBAS	--	60 - 90	0.2 - 1.5 mg/L
4.	Suspended Solids	75 - 90	70 - 95	15 - 100 mg/L*
5.	Algae	--	--	150 - 300 mg/L
6.	Phosphorus as PO_4			5 - 20 mg/L

* Includes algae.

Note: Since industrial wastes are varied and specific for each process, effluent quality values may not apply. Industrial pollution loading may be based on units of production or total daily output of pollutional substances.

Table D.5. U.S.A. PERFORMANCE STANDARDS FOR WASTE WATER DISCHARGED AFTER APPLICATION OF THE BEST AVAILABLE DEMONSTRATED CONTROL TECHNOLOGY BY NEW SOURCES OF THE COAL MINING POINT SOURCE CATEGORY(1)

Bituminous, Lignite and Anthracite Mining

Parameter	Coal Preparation Plants and Associated Area		Acid or Ferruginous Mine Drainage(2)		Alkaline Mine Drainage(2)	
	1-Day Maximum	Average of 30 Consecutive Daily Values	1-Day Maximum	Average of 30 Consecutive Daily Values	1-Day Maximum	Average of 30 Consecutive Daily Values
Total Suspended Solids (mg/L)	70.0	35.0	70.0(3)	35.0(2)	70.0(3)	35.0(3)
Total Iron (mg/L)	6.0	3.0	6.0	3.0	6.0	3.0
Total Manganese (mg/L)	4.0	2.0	4.0	2.0	--	--
pH (pH units)	range 6.0-9.0		range 6.0-9.0		range 6.0-9.0	

(1) The limitations are not applicable to excess water discharged as a result of precipitation or snow melt in excess of the 10-year, 24 hour precipitation went (40 CFR 434; 44 FR9: 2586--2592; 12 January 1979).

(2) Drainage which is not from an active mining area (for example, a regraded area) is not required to meet the stated limitations, unless it is mixed with untreated mine drainage that is subject to the limitations.

(3) Total suspended solids limitation do not apply in Colorado, Montana, North Dakota, South Dakota and Wyoming. In these states, limitations for the total suspended solids are determined on a case by case basis.

Appendix E

MAJOR AND MINOR TRACE ELEMENT ENRICHMENT RATIO'S IN GASIFIER RESIDUES

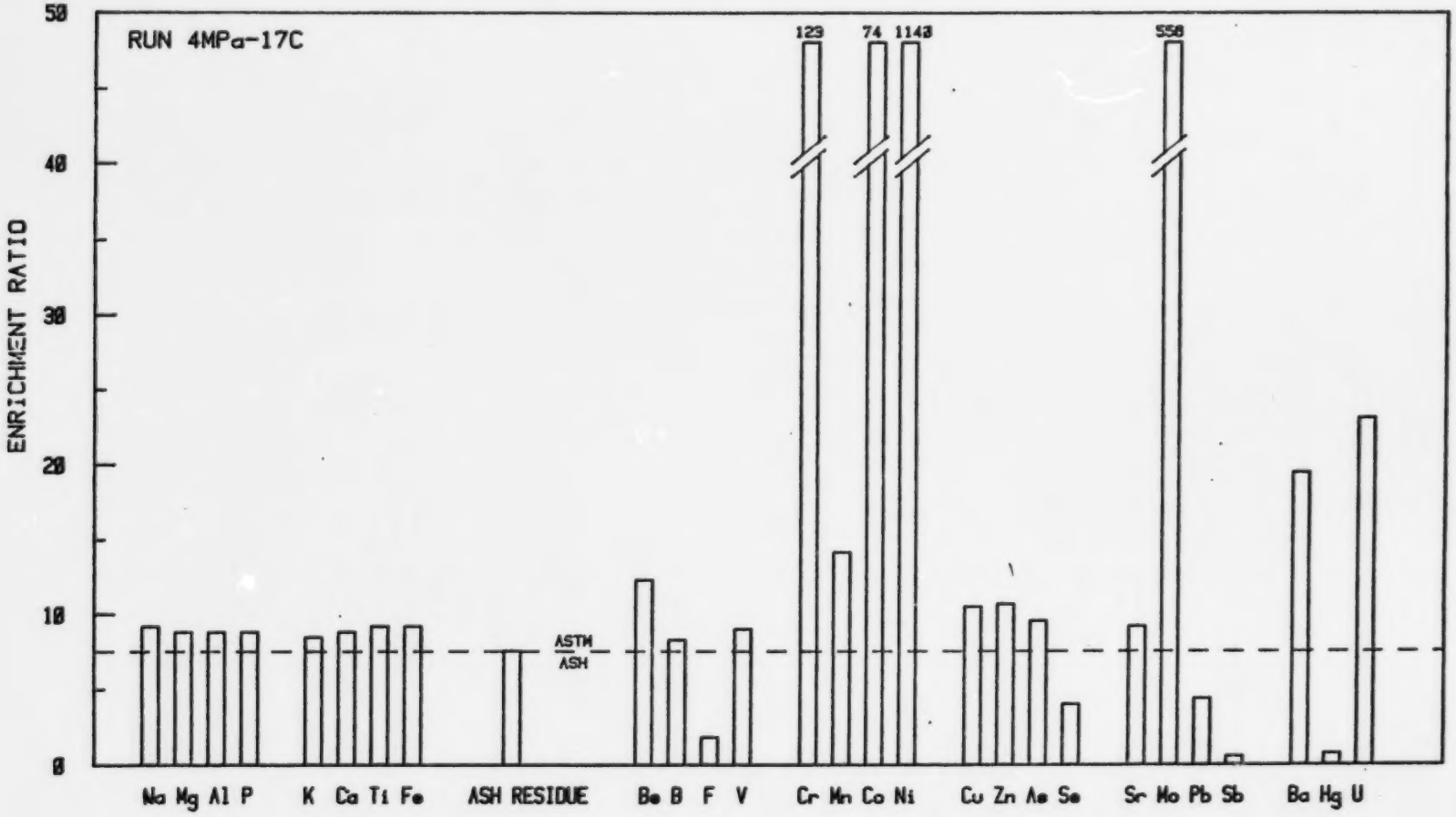


Figure E.1. MAJOR AND TRACE ELEMENT ENRICHMENT RATIO'S IN GASIFIER RESIDUE: RUN 17C-4MPa

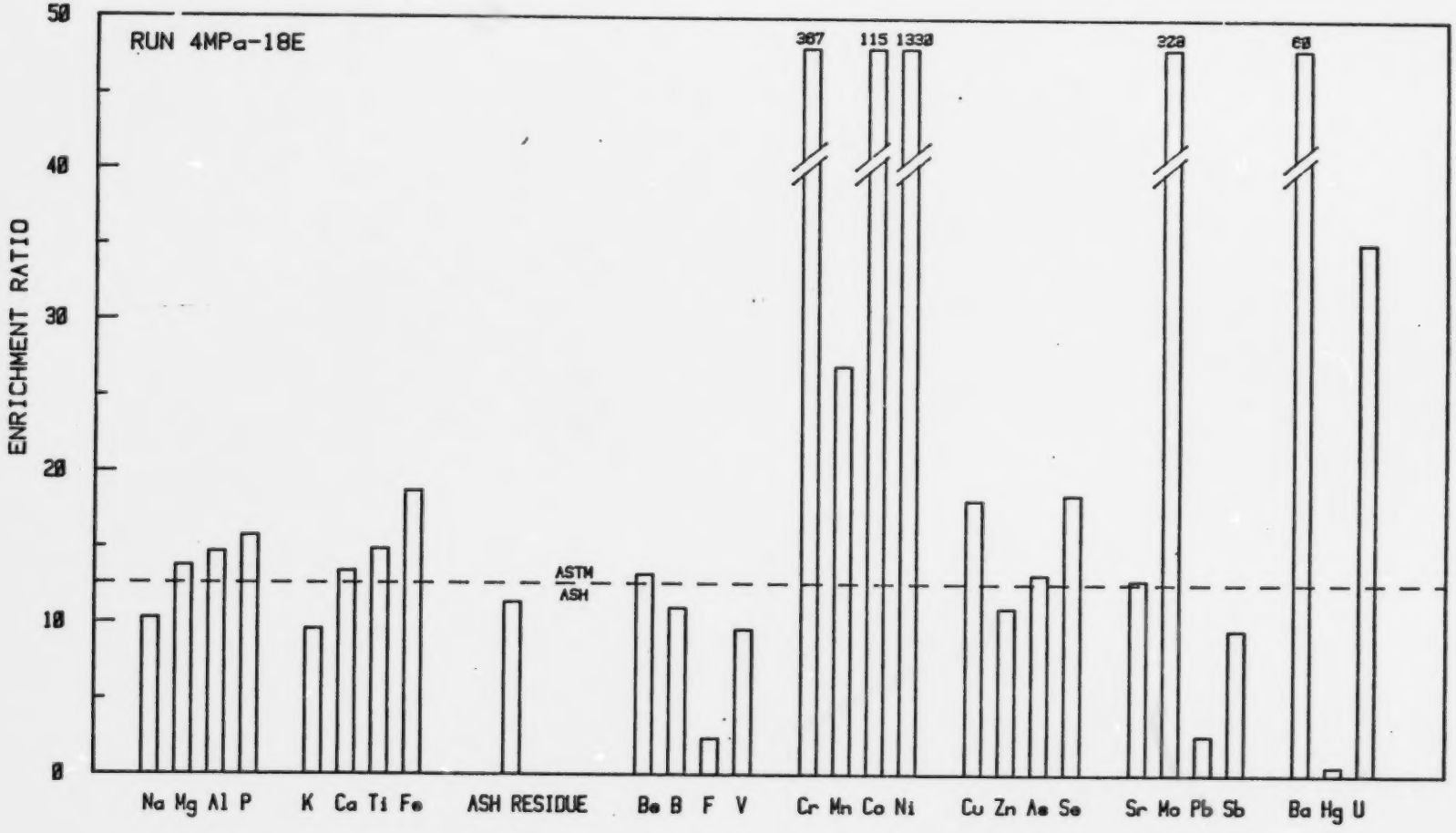


Figure E.2. MAJOR AND TRACE ELEMENT ENRICHMENT RATIO'S IN GASIFIER RESIDUE: RUN 18E-4MPa

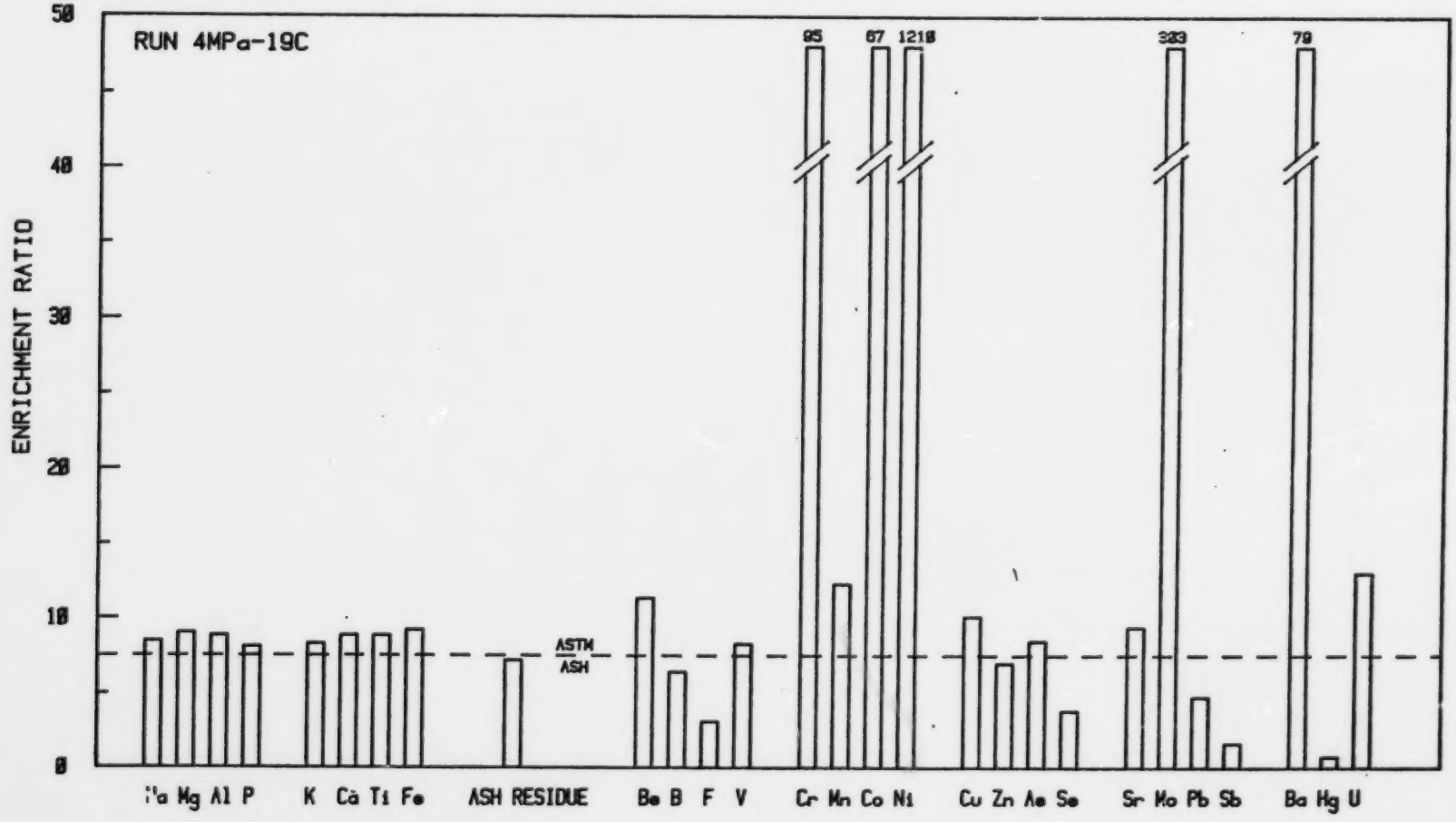


Figure E.3. MAJOR AND TRACE ELEMENT ENRICHMENT RATIO'S IN GASIFIER RESIDUE: RUN 19C-4MPa

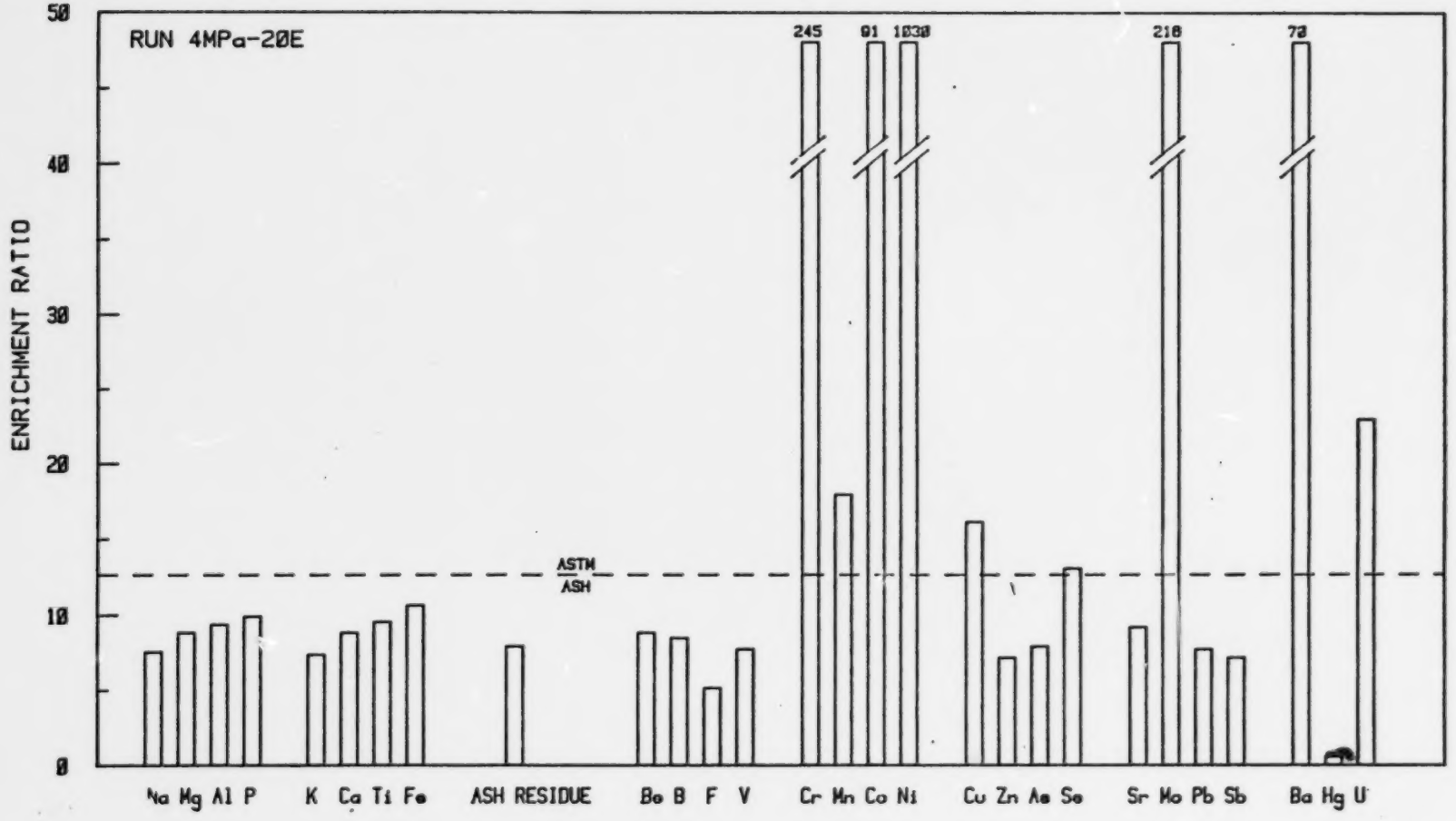


Figure E.4. MAJOR AND TRACE ELEMENT ENRICHMENT RATIO'S IN GASIFIER RESIDUE: RUN 20E-4MPa

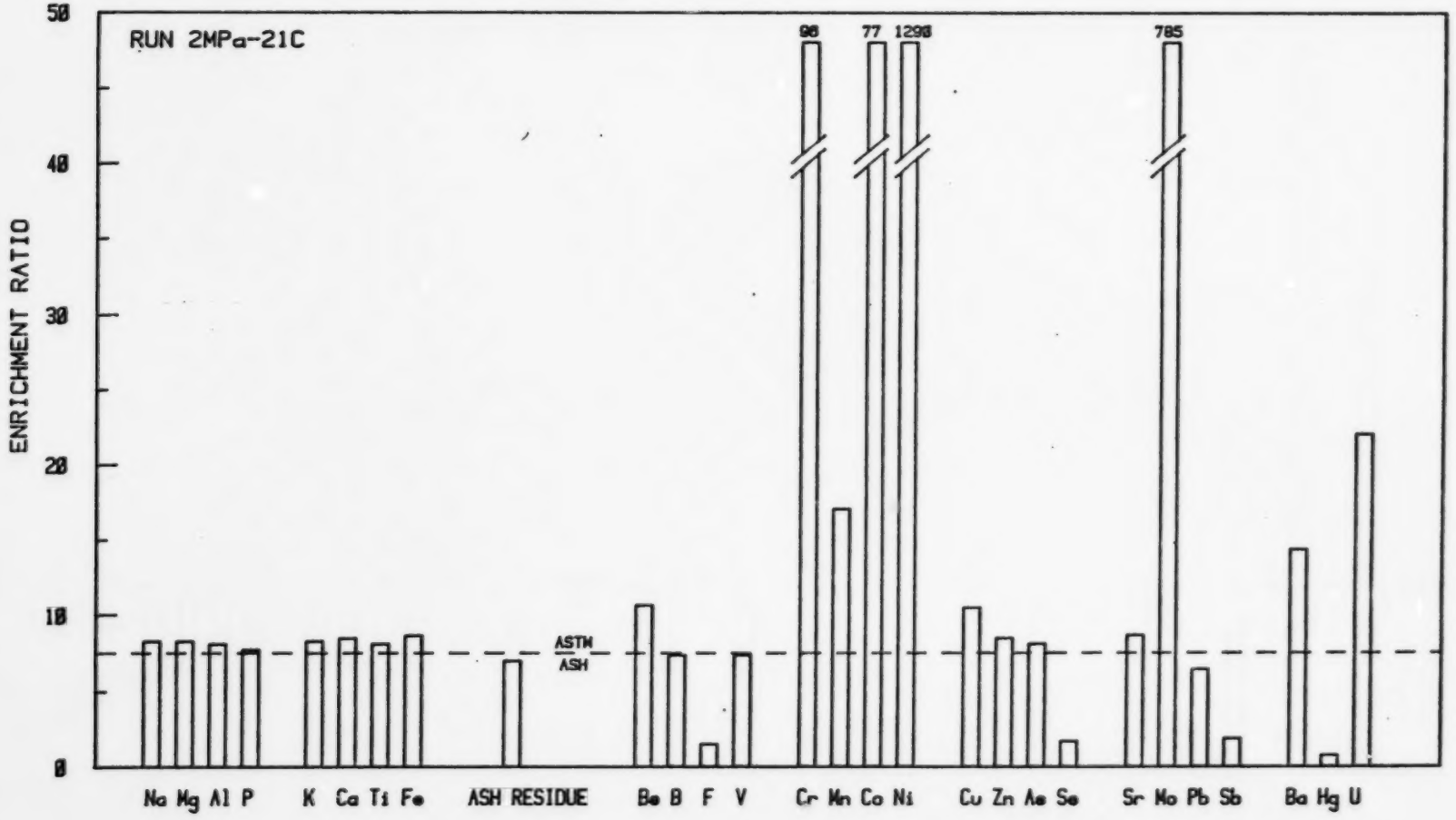


Figure E.5. MAJOR AND TRACE ELEMENT ENRICHMENT RATIO'S IN GASIFIER RESIDUE: RUN 21C-2MPa

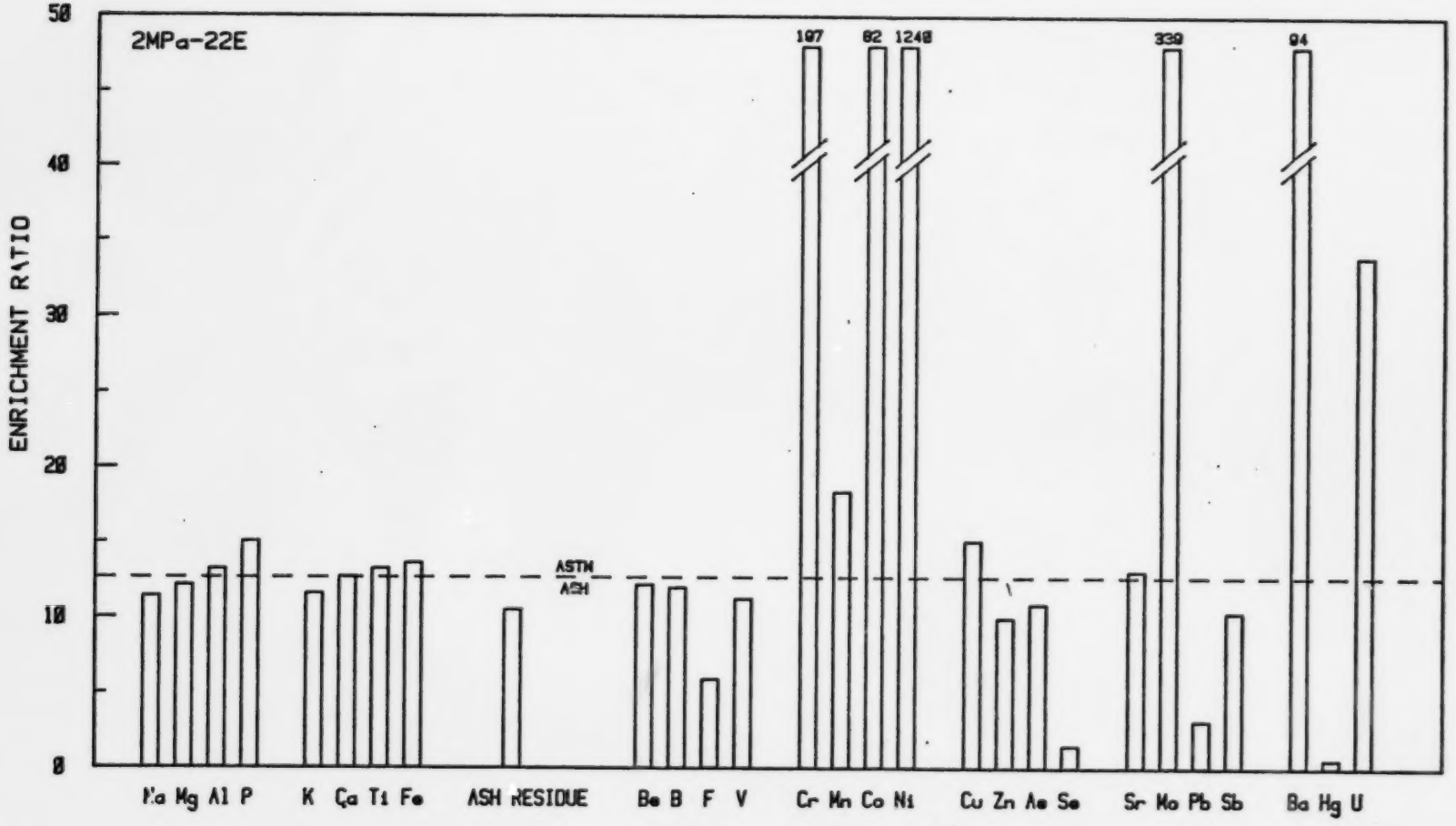


Figure E.6. MAJOR AND TRACE ELEMENT ENRICHMENT RATIO'S IN GASIFIER RESIDUE: RUN 22E-2MPa

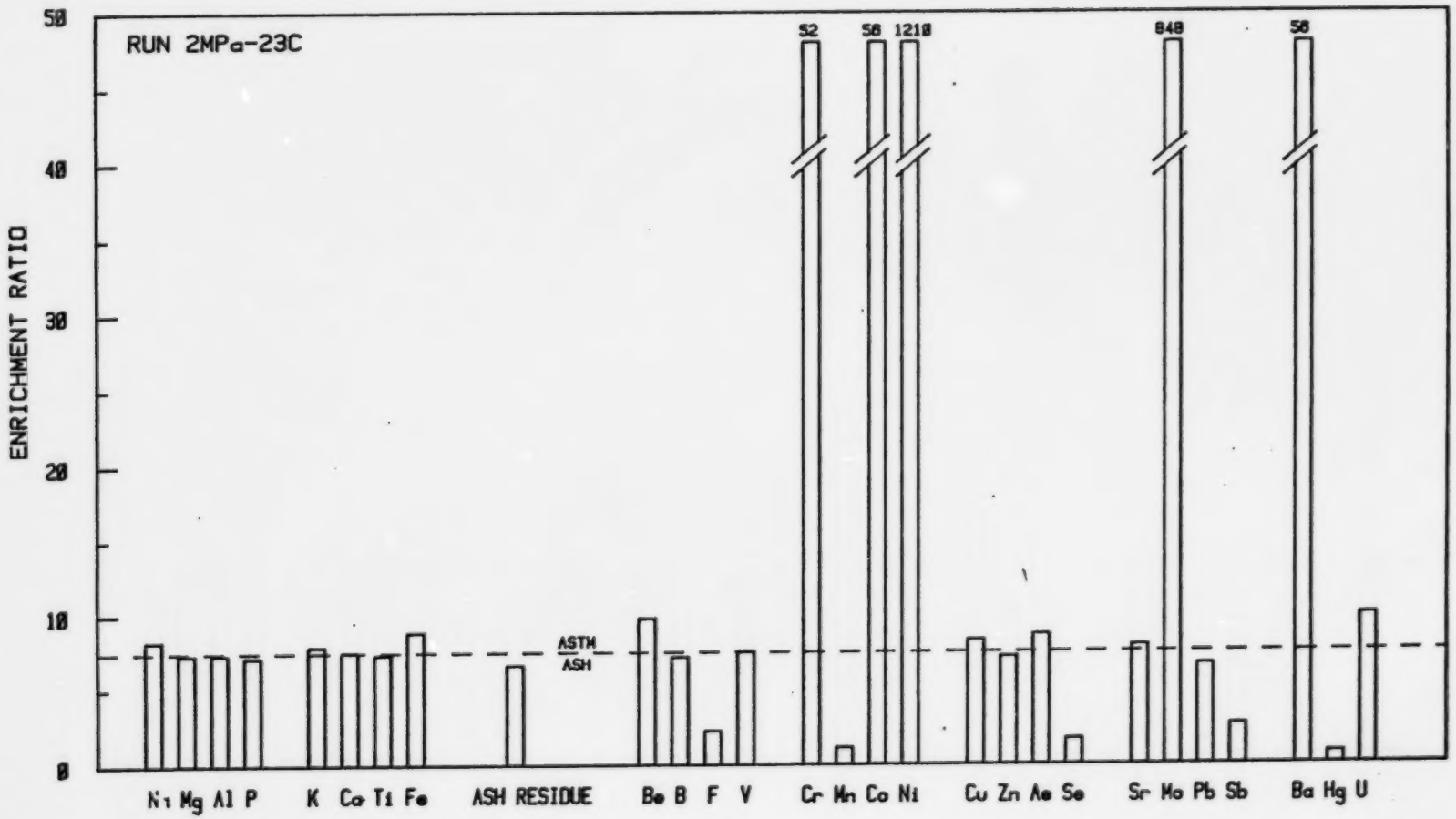


Figure E.7. MAJOR AND TRACE ELEMENT ENRICHMENT RATIO'S IN GASIFIER RESIDUE: RUN 23C-2MPa

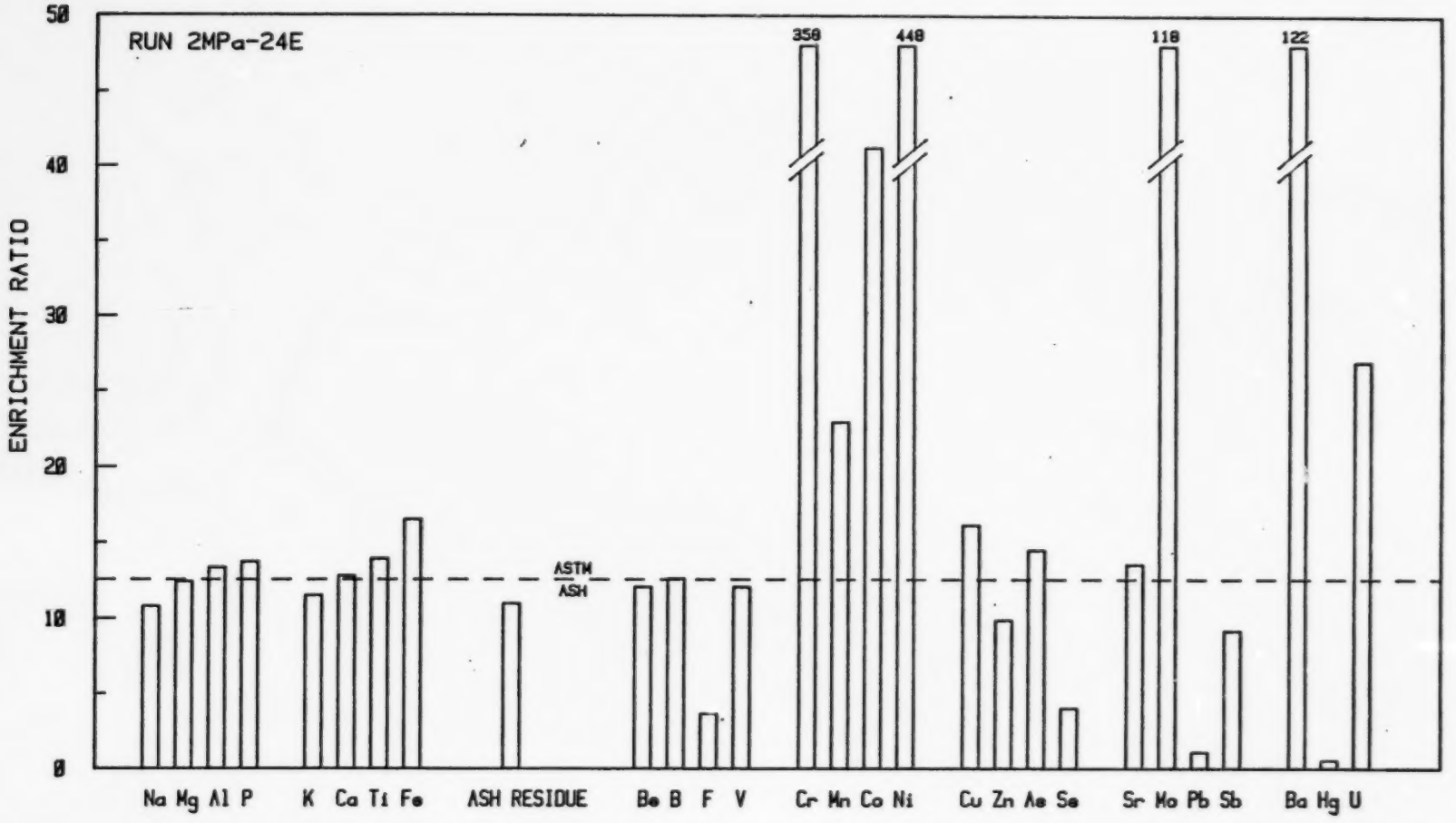


Figure E.8. MAJOR AND TRACE ELEMENT ENRICHMENT RATIO'S IN GASIFIER RESIDUE: RUN 24E-2MPa

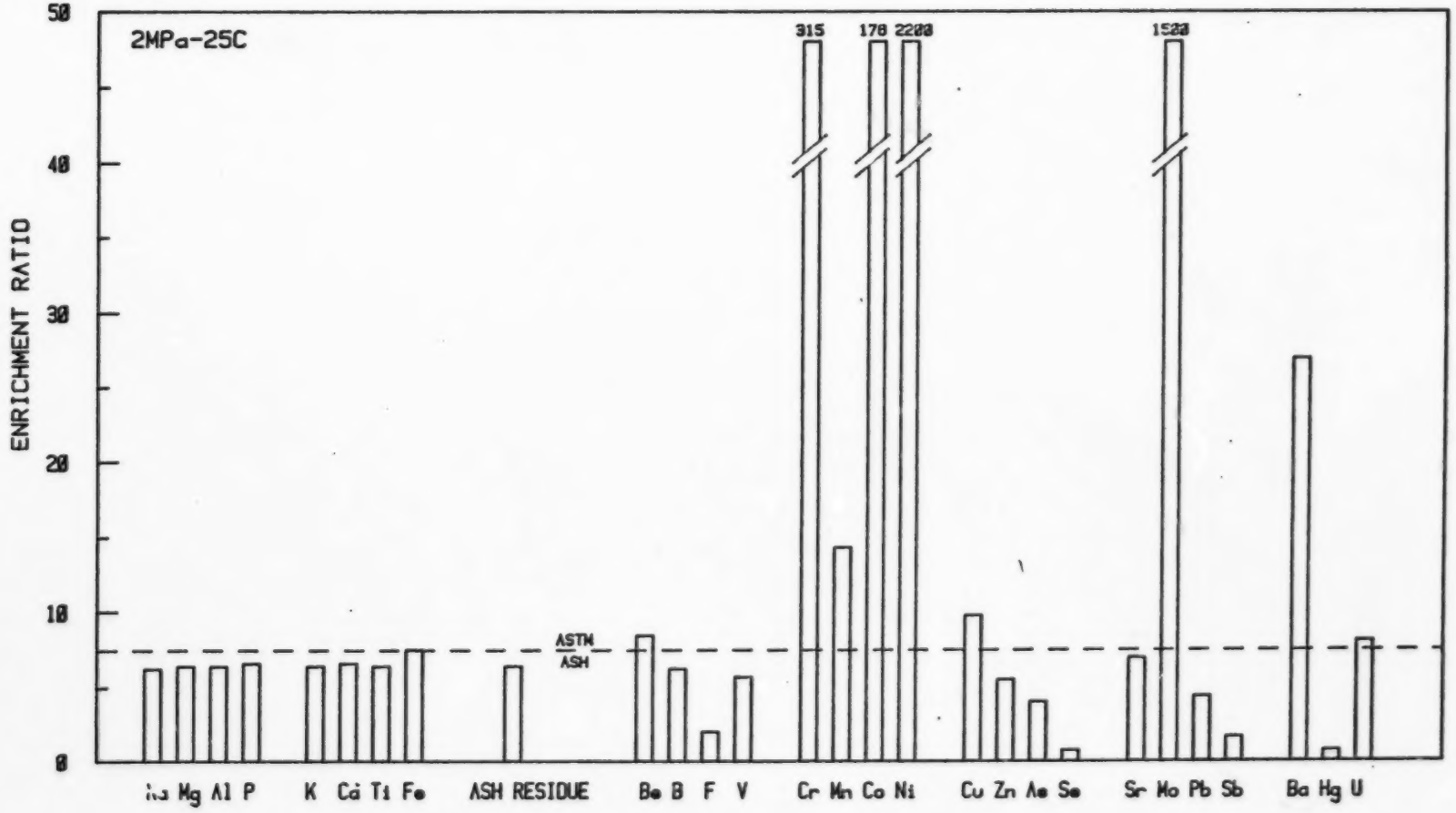


Figure E.9. MAJOR AND TRACE ELEMENT ENRICHMENT RATIO'S IN GASIFIER RESIDUE: RUN 25C-2MPa

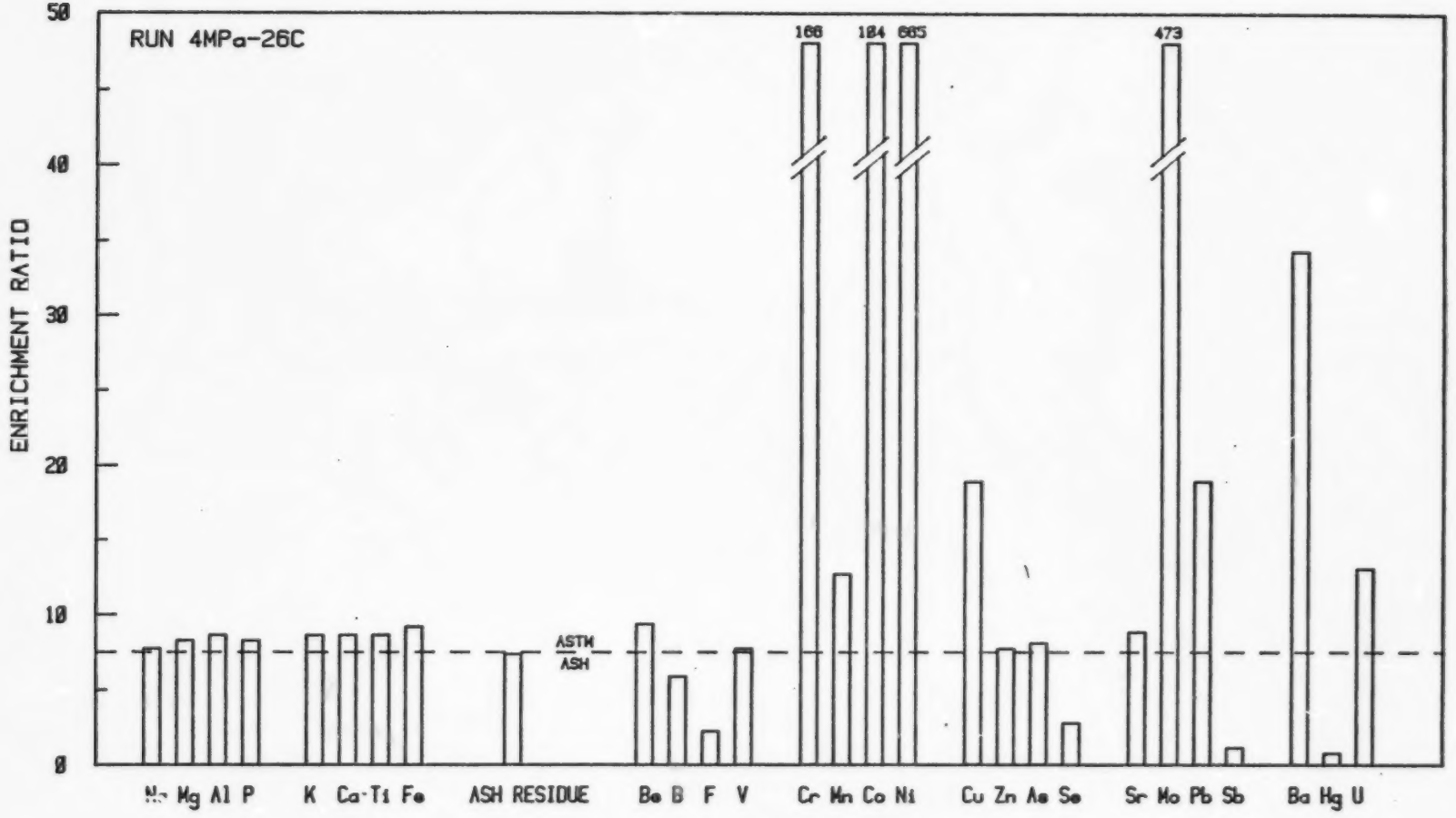


Figure E.10. MAJOR AND TRACE ELEMENT ENRICHMENT RATIO'S IN GASIFIER RESIDUE: RUN 26C-4MPa

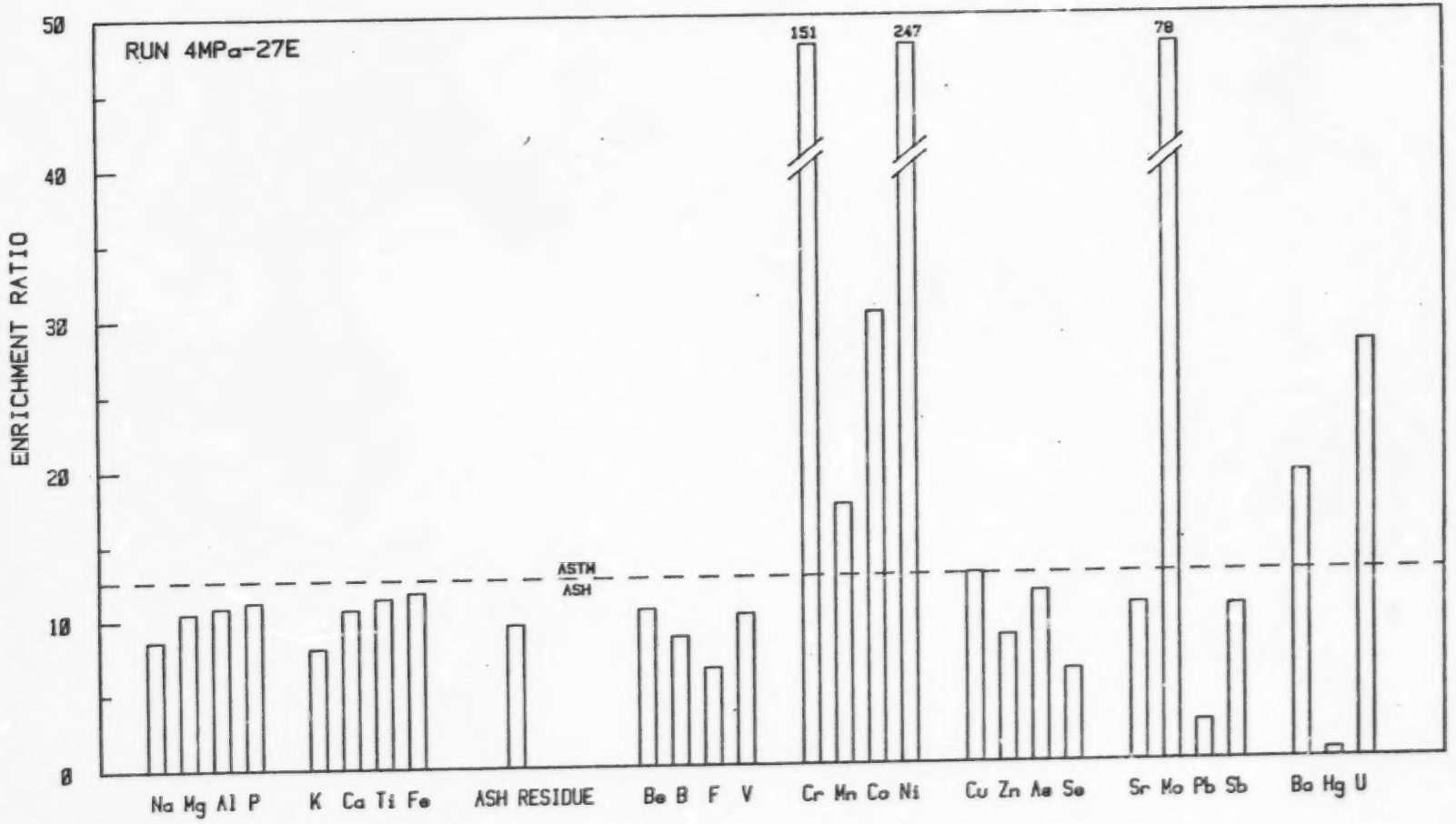


Figure E.11. MAJOR AND TRACE ELEMENT ENRICHMENT RATIO'S IN GASIFIER RESIDUE: RUN 27E-4MPa

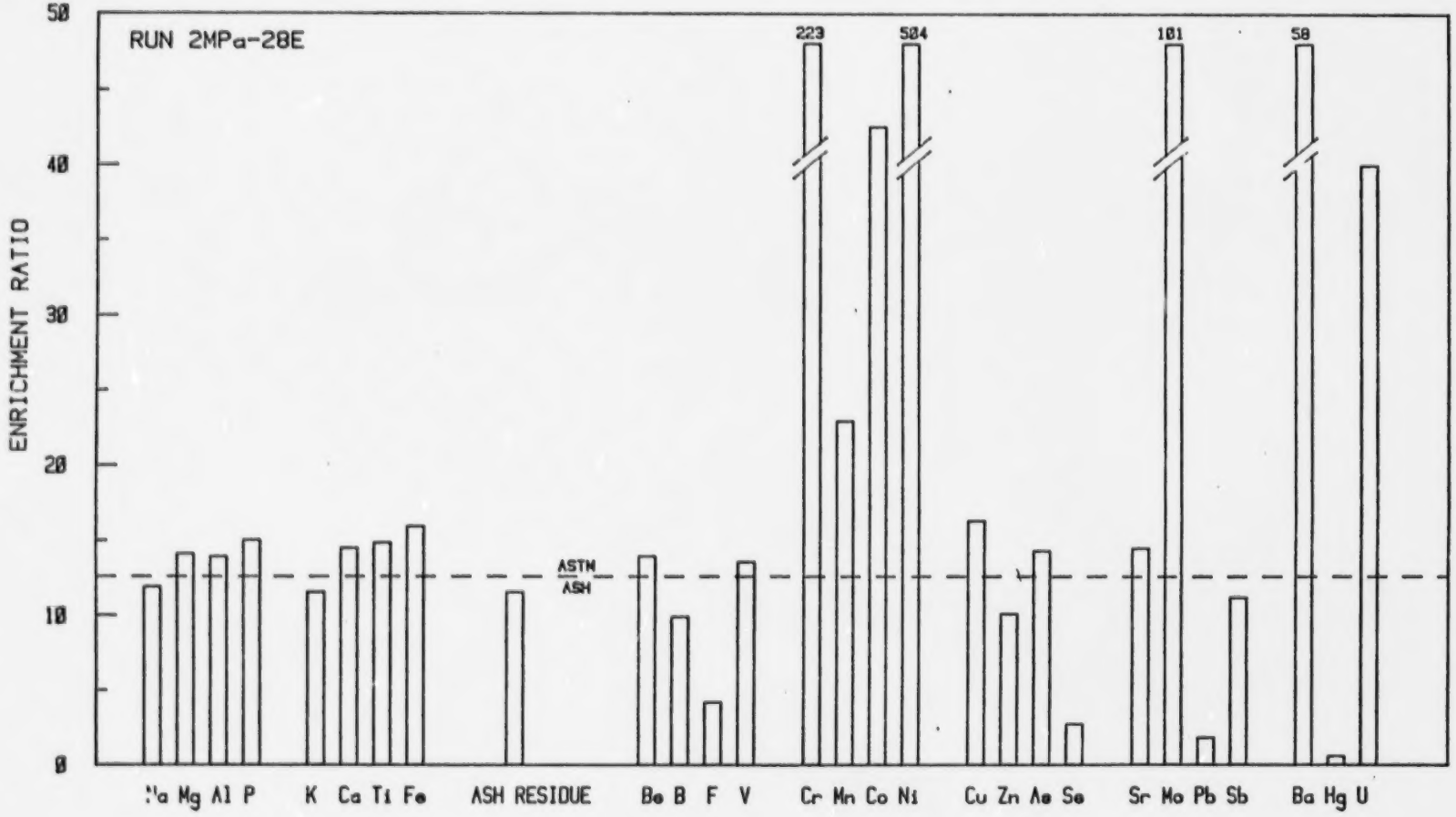


Figure E.12. MAJOR AND TRACE ELEMENT ENRICHMENT RATIO'S IN GASIFIER RESIDUE: RUN 28E-2MPa